

STOCK ASSESSMENT OF THE CHOKKA SQUID

Loligo vulgaris reynaudii

Beatriz A. Roel

Submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy at the University of Cape Town

Supervisors: Professor J. G. Field

Professor D. S. Butterworth

Dr K. L. Cochrane

August 1998

The University of Cape Town has been given
the right to reproduce this thesis in whole
or in part. Copyright is held by the author.

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

DECLARATION

In this thesis, I report on the results of original research I carried out at the Sea Fisheries Research Institute (SFRI) between 1994 and 1998. The ideas presented are largely my own, although data were obtained from a number of sources.

Squid catch and effort data from the demersal trawl fishery were supplied by Ms Jean P. Brown, who extracted them from the SFRI demersal data base. Catch and effort data for the jig fishery were extracted by myself from the SFRI linefish data base. Biomass estimates from the South Coast surveys were supplied by technical staff of the SFRI. I planned and designed the questionnaire addressed to the chokka boat owners, but called on the assistance of the SFRI technical staff. My colleague Mr J. A. A. De Oliveira provided focus in solving the equations for the projected catches in the observation-error models. I carried out all the SAS programming and data analysis procedures. The models used in the study to assess the status of the chokka squid resource were run on a Brother computer with Pentium processor. The models were coded in FORTRAN and I wrote the programmes myself. Most of the graphic work was produced by myself.

Much of Chapter 5 has been accepted for publication in the *South African Journal of Marine Science*. It is co-authored by myself (as senior author), Dr K. L. Cochrane and Prof. D. S. Butterworth. For the paper, I did all the analyses under the supervision of Prof. Butterworth. Dr Cochrane provided direction on some of the management considerations, developed some of the ideas and gave constructive criticism at various stages of the research.

This work has not been submitted for a degree at any other university and any assistance I received during the course of its completion is fully acknowledged.

DECLARATION

In this thesis, I report on the results of original research I carried out at the Sea Fisheries Research Institute (SFRI) between 1994 and 1998. The ideas presented are largely my own, although data were obtained from a number of sources.

Squid catch and effort data from the demersal trawl fishery were supplied by Ms Jean P. Brown, who extracted them from the SFRI demersal data base. Catch and effort data for the jig fishery were extracted by myself from the SFRI linefish data base. Biomass estimates from the South Coast surveys were supplied by technical staff of the SFRI. I planned and designed the questionnaire addressed to the chokka boat owners, but called on the assistance of the SFRI technical staff. My colleague Mr J. A. A. De Oliveira provided focus in solving the equations for the projected catches in the observation-error models. I carried out all the SAS programming and data analysis procedures. The models used in the study to assess the status of the chokka squid resource were run on a Brother computer with Pentium processor. The models were coded in FORTRAN and I wrote the programmes myself. Most of the graphic work was produced by myself.

Much of Chapter 5 has been accepted for publication in the *South African Journal of Marine Science*. It is co-authored by myself (as senior author), Dr K. L. Cochrane and Prof. D. S. Butterworth. For the paper, I did all the analyses under the supervision of Prof. Butterworth. Dr Cochrane provided direction on some of the management considerations, developed some of the ideas and gave constructive criticism at various stages of the research.

This work has not been submitted for a degree at any other university and any assistance I received during the course of its completion is fully acknowledged.

Beatriz Adelaida Roel

*To my children Juan Pablo and Dylan, who have been
with me all along the way; and to my parents.*

*A mis hijos Juan Pablo y Dylan, que me acompañaron;
a mis padres.*

TABLE OF CONTENTS

DECLARATION	ii
ABSTRACT	viii
SUMMARY	ix
ACKNOWLEDGEMENTS	xi
1. Introduction	1
1.1 <u>Background</u>	
1.1.1 Definition of the problem and objectives of study	
1.1.2 Review of stock assessments of other cephalopod resources	
1.1.3 Management approaches taken in other squid fisheries	
1.1.4 Socio-political context. Background to history of utilization, current pressures with focus on jig fishery.	
1.1.5 Current management approach for the chokka squid in South Africa	
1.2 <u>Objectives</u>	
1.2.1 Objectives of study: to produce a management recommendation for the economically important squid jigging fishery based on rigorous assessment of the stock	
1.2.2 General description of the data available and methods used in the study	
1.2.3 Hypotheses examined in this study	
2. Review of current knowledge on the life-cycle of chokka squid	27
2.1 Time-scale of the larvae, juvenile, sub-adult and adult stages. Average lifetime	
2.2 Duration and conditions related to spawning and hatching	
2.3 Average life-span	
2.4 Spatial distribution of juveniles, pre-adults and adults	
2.5 Migration cycle	
2.6 Assumptions made in the assessment on the life cycle of chokka squid	

2.7 A conceptual model of the species' population dynamics

3. Dynamics of the South Africa's two chokka squid fisheries

41

3.1 The jigging fishery

- 3.1.1 Composition of the fishing fleet
- 3.1.2 Choice of units to express jigging CPUE
- 3.1.3 Temporal trends in effort
- 3.1.4 Spatial distribution of fishing effort.

3.2 Chokka taken as by-catch in the demersal finfish trawl fishery.

- 3.2.1 Data
- 3.2.2 Distribution of fishing effort. Spatial and temporal patterns
- 3.2.3 Annual CPUE trend
- 3.2.4 Influence of possibly directed catches
- 3.2.5 CPUE by area and by depth range

3.3 Conclusions

- 3.3.1 The directed jig fishery
- 3.3.2 The trawl by-catch fishery

4. Analysis of the data available for model-estimation procedures

81

4.1 Index of abundance derived from the trawl by-catch fishery

- 4.1.1 Data
- 4.1.2 Identifying outliers in the drag-by-drag data before accumulation
- 4.1.3 The GLM model
- 4.1.4 Results

4.2 CPUE data from the jig fishery

- 4.2.1 GLM analysis using two years of data
- 4.2. 2 Results

4.3 Biomass estimates from demersal surveys

- 4.3.1 Data
- 4.3. 2 Examination of trends in the biomass estimates

4.4 Conclusions

5. Investigation on the effects of different levels of effort and of the closed

111

season in the jig fishery for chokka squid *Loligo vulgaris reynaudii*

5.1 Introduction

5.2 Material and methods

5.2.1 Data

5.2.2 Modelling the biomass dynamics on the spawning grounds.

5.2.3 Bootstrap estimation of confidence intervals

5.2.4 Projections

5.3 Results and discussion : Evaluation of the effects of different effort levels and of the closed season.

5.4 Conclusions

6. Application of a biomass-based model to fit time-series of biomass indices 133

6.1 Introduction

6.2 Material and methods

6.2.1 Data

6.2.2 The model

6.2.3 General properties of the basic model used

6.2.4 Splitting the year

6.2.5 Bootstrap estimation of confidence intervals

6.2.6 Projections

6.2.7 Sensitivity tests

6.3 Results and discussion.

6.4 Conclusions

7. Assessment, considering possible negative impacts of the jig fishery's disturbance of spawning aggregations on recruitment 165

7.1 Introduction

7.2 Material and methods

7.2.1 The model

7.2.2 Data

7.3 Results and discussion

7.4 Conclusions

8. Conclusions and recommendations	179
8.1 <u>Introduction</u>	
8.2 <u>The chokka-directed fishery</u>	
8.3 <u>Data</u>	
8.3.1 Trawl index of abundance	
8.3.2 Jig CPUE	
8.3.3 Biomass estimates from scientific surveys	
8.4 <u>Modelling approaches</u>	
8.5 <u>Stock-recruitment relationship</u>	
8.6 <u>Status and productivity of the resource</u>	
8.5.1 Comparison of results from the process-error and the observation-error estimators	
8.5.2 Observation-error estimator. Comparison of results from the two approaches taken to model recruitment	
8.7 <u>Management recommendations</u>	
8.8 <u>Future work</u>	
8.9 <u>Conclusion</u>	
 LITERATURE CITED	 199
 APPENDIX: Catch and CPUE data from the jig and trawl fisheries	 211

ABSTRACT

AUTHOR'S FULL NAME: Beatriz Adelaida ROEL OLIVE (married to A.I.L. PAYNE)

ADDRESS: 5 Krom Rd, Bergvliet, 7945, SOUTH AFRICA

THESIS TITLE: Stock Assessment of the Chokka Squid, *Loligo vulgaris reynaudii*

The primary aim of the study was to assess the status and productivity of chokka squid. Main hypotheses examined are the following:

- that the sharp decline in the trawl fishery catch per unit effort (CPUE) data in the early 1980s, reflects a real decline in the trawlers catch rate;
- that the decline in the trawl CPUE index is caused by the jig fishery removing the biomass that otherwise would be available to the trawl fishery;
- that the jig fishery “disturbs” the spawning process and causes a decline in subsequent recruitment.

Catch and effort data from the two fisheries, as well as biomass estimates from spring and autumn research surveys, were used. The two main fisheries and the catch and effort data are described. General Linear Modelling (GLM) was performed on the CPUE data from the trawl fishery in order to obtain annual indices of abundance. Further, results from a GLM analysis on two years of monthly jig CPUE data are presented.

The dynamics of the stock biomass on the spawning grounds were modelled in order to assess the effects of current levels of effort and the existing closed season on the resource. The dynamics of the stock and the fishery were captured by a simple biomass-based model. Two dynamic methods were used to estimate model parameters: 1. a process-error estimator; 2. an observation-error estimator. All model parameter were estimated by maximum likelihood, and the corresponding confidence intervals were estimated by bootstrapping.

Significant findings in relation to the main hypotheses listed above are the following:

- that the decline in trawl CPUE reflects a real decline in the trawlers’ by-catch of chokka and is not the result of changes in fishing patterns, strategy and/or fleet composition;
- that the decline in the trawl CPUE index reflects a change in relative local abundance of chokka;
- that the quantities taken by the jig fishery were not, alone, sufficient to cause that decline;
- that the hypothesis of the jig fishery “disturbing” the spawning process and causing a decline in subsequent recruitment, is more consistent with the data than the second hypothesis listed above.

Overall, this thesis makes a contribution to a better understanding of the dynamics of the chokka fishery in South Africa and of the response of chokka to alternative management options selected in the context of a constant proportion harvesting strategy.

SUMMARY

The South African chokka squid *Loligo vulgaris reynaudii* is caught by a local jig fishery, which targets primarily spawning aggregations off the South Coast, and as a by-catch in an inshore trawl fishery, which targets Cape hake (*Merluccius* spp.) and Agulhas sole (*Austroglossus pectoralis*). The most important tool used to manage the fishery currently is effort control. Some other measures, such as implementation of a closed season, are also in place.

The primary aim of the study was to assess the status and productivity of chokka. Catch and effort data from the two fisheries, as well as biomass estimates from spring and autumn research surveys, were used. The catch and effort data of the two main fisheries are described. A General linear modelling (GLM) is performed on the catch per unit effort data from the trawl fishery (trawl CPUE) in order to obtain annual indices of abundance. Results from a GLM analysis on two years of monthly jig CPUE data are presented. Trends in the biomass estimates deduced from the swept area research surveys are also examined.

The dynamics of the stock biomass on the spawning grounds were modelled in order to assess the effects of current levels of effort and the existing closed season on the resource. Two methods are used to estimate model parameters: 1. a process-error estimator, which assumes that process error dominates over observation error; 2. an observation-error estimator, which assumes that the error occurs in the relationship between the biomass and the index of abundance. All model parameter were estimated by maximum likelihood, and the corresponding confidence intervals were estimated by bootstrapping.

1. In the case of the process-error estimator, monthly jig CPUE data were fitted. The model has three parameters: g , a parameter which combines natural mortality, emigration and somatic growth; q , catchability; and I , which represents immigration to the spawning grounds. The estimates of the parameters were used to project the stock biomass forward in time to evaluate the impact of various effort levels both with and without a closed season. Results indicate that the biological and economic gains provided by the current closed season are smaller than intuitively thought and further that there is not much justification for urgent action to curtail current effort levels. However, in view of the estimated high risk associated with the current levels of effort and the great sensitivity shown by the results to basic model assumptions, both maintenance of the closed season and a need to avoid increases above the current level of effort are recommended herein. Further, the level of effort may need to be reduced, and the option of lengthening an existing closed season to effect this may well prove easier to implement than any attempt to reduce the present number of participants in the fishery.

2. The jig CPUE, the trawl index and the two biomass indices from scientific surveys were fitted in the observation-error estimator. The dynamics of the stock and of the fishery were simulated in

two periods, January – March and April – December, to obtain a better approximation to the timing of the surveys and to the dynamics of the two fisheries. Parameters estimated are the recruitment R and the catchability coefficients corresponding to each biomass index; the composite parameter g is fixed externally. Within this approach, two different models were used for annual recruitment: a) recruitment was constant above the biomass threshold at which it started to decline, and b) the recruitment level depends on jig-induced fishing mortality, larger values of which produce increasingly negative impact on reproductive success.

2a) The estimated parameters had wide confidence intervals and the model could not fit the decline in the early years of the trawl CPUE time-series. Stochastic 10-year projections of the stock biomass were performed to evaluate the impact on the resource of different levels of effort. Results in terms of the performance statistics, for the assumptions corresponding to the base case, suggest that sustainable yields may be higher than recent catches. However, the associated risk, or probability of the spawning biomass falling below 20% of the pristine level, is very high, and the results are generally very sensitive to model assumptions.

2b) A variation of the above model was developed, with recruitment depending on the ratio of the jig catch to the spawning biomass. The model incorporated an additional parameter N , which was fixed externally. A better fit was achieved with this approach. This model estimates current biomass to be severely depleted. Stochastic projections for the assumptions corresponding to the base case showed that the risk of the spawning biomass falling below 20% of pristine, associated with the current fishing effort, is close to 90%. However, reducing present effort by 1/3 of that existing at present would reduce the level of risk to just above 20%, and sustainable annual catches would be of the order of 5300 tons, compared to 4 168 tons under the present regime. Some alternative scenarios that were investigated, such as a non-linear relationship between jig CPUE and biomass, gave a more pessimistic assessment.

The uncertainty associated with the estimates of current stock size and associated productivity was identified as a key element in this assessment. The risk of the spawning biomass falling below 20% of its pristine level was found to be high compared to other short-lived species, even without fishing. This is because the risk assessment is based on estimates of current biomass levels which suggest that the stock is already severely depleted. Therefore, even without fishing, the resource would take a few years to recover to safer levels. The impact of various levels of effort reduction was evaluated in terms of their impact on risk and on expected sustainable annual catches. The biological risks evaluated in this study will have to be considered in conjunction with the socio-economic consequences of possible reductions in fishing effort, if responsible management decisions are going to be made to ensure sustainable utilisation of this valuable resource.

ACKNOWLEDGEMENTS

I thank my colleagues in the Stock Assessment Division of the Sea Fisheries Research Institute (SFRI) and in the Squid Working Group for their support, particularly during the final stretch of my work on this thesis, when they facilitated my completion of the work in time. In particular, I am particularly appreciative of the discussions of various aspects of the modelling work I had with Mr Jose A. A. de Oliveira and for the time and experience on GLM analyses so willingly given by Ms Jean P. Brown.

In terms of technical assistance, I acknowledge the in-house inputs provided by Mr Shawn Berry, Ms Dagmar Merkle, Ms Janine Nelson, Ms Megan Terry, and Ms Iona Styles in terms of data capture, data checking, plotting and reference list overhaul. Specifically, I wish to acknowledge Mr M. Prowse for the friendly and professional manner in which he coordinated technical assistance whenever it was required and also helping to solve various word processing and plotting software problems.

My bibliographic searching was also facilitated by the capable assistance of Mrs A. Meltzer in the SFRI Gilchrist Library. Industry background from Mr R. Ball (Suiderland), who willingly shared his broad knowledge of the jig fishery, and Mr C. A. Atkins (I & J), who provided focus on trawl by-catches, is sincerely acknowledged.

I thank my supervisors: Dr Kevern L. Cochrane (F.A.O., Rome), for his support and advice, for his ideas and his many valuable comments on the manifold drafts; Prof. Doug S. Butterworth, for his expert supervision of the modelling and mathematical work and for thorough comments on the final draft in particular; and Prof. John G. Field, for enthusiastically guiding me to the point of submission and for very useful comments on the final draft.

Finally, and most importantly, I wish to sincerely acknowledge the support and encouragement that I received from my family and friends, some in the SFRI, who helped me to persevere and to see the project through. In particular, I wish to thank my close family in South Africa: Sian, Dylan and Andrew for their loving support and for freeing my time from the many household commitments. Specially, I wish to thank my husband Andrew for many hours devoted to editing and improving the quality of this manuscript, for his patience and positive attitude during the times of frantic work and when everything seemed to fail and, in general, for being there when I most needed support.

CHAPTER 1

Introduction

1.1 BACKGROUND

1.1.1 Definition of the problem and objectives of study

The chokka squid *Loligo vulgaris reynaudii* is caught mainly off the Eastern Cape, a province located in the south-eastern part of South Africa. The coastline covered by the chokka fishery is approximately 1000 km long and extends from Mossel Bay to East London (Fig. 1.1). During the 1970s and early 1980s, local and foreign vessels trawled squid, but there was no jigging. While the local trawl fleet targeted mainly on hake (*Merluccius* spp.) or, to a lesser extent sole (*Austroglossus pectoralis*), and squid was only a by-catch, squid were eagerly exploited by Japan from around 1974 to meet an increasing domestic (in Japan) demand for loliginid squid (Sato and Hatanaka 1983). In recent years, however, approximately 80% of the annual chokka catch is caught by a directed jig fishery (Fig. 1.2). This jig fishery originally targeted on chokka spawning aggregations, which occur seasonally in waters generally no deeper than 40 m. However, the fishery has gradually developed the technology to fish farther offshore on the chokka feeding grounds to be able to operate virtually throughout the year.

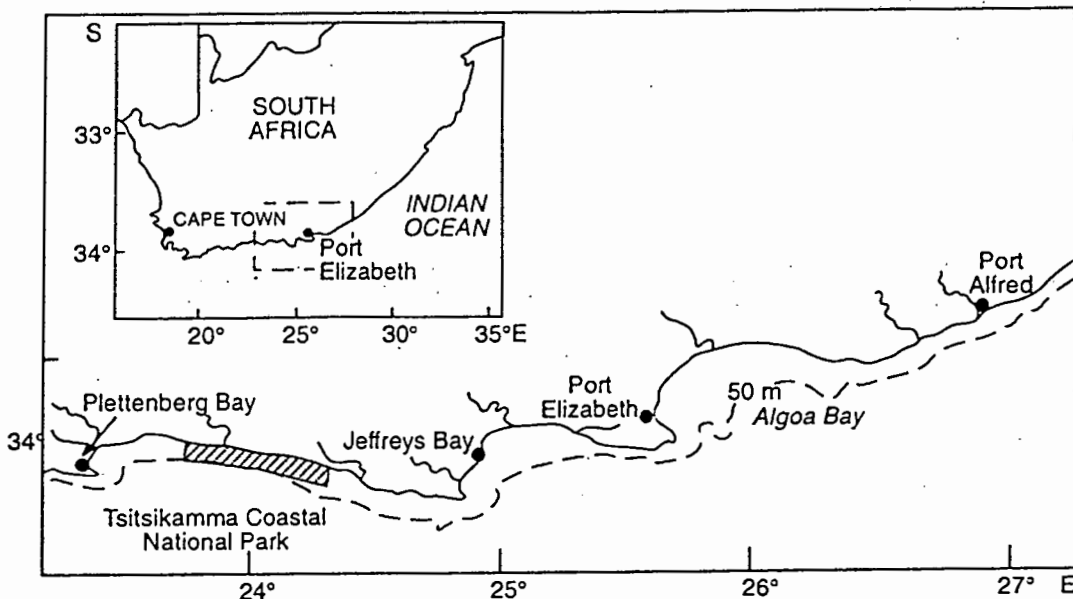


Fig. 1.1: Main area of operation of the jig fishery for chokka squid *Loligo vulgaris reynaudii*.

The chokka fishery has a high economic value, not so much because of the magnitude of the catch, which has never surpassed 10 000 tons per year, but as a result of the value of its product which is close to US\$ 6 per kg (R. Ball pers. comm.). Chokka squid is mainly exported, freshly frozen, to the European markets, where it commands a high price (Augustyn *et al.* 1992). At the level of the South African national fishing industry it is, on average, probably placed fifth in economic value after the demersal, pelagic, rock lobster and abalone fisheries, the value at first sale of the chokka catch in 1995 having been close to R104 million (Cochrane *et al.* 1997). Furthermore, the chokka fishery is of great importance particularly in the Eastern Cape, both as a source of income for the region and because it supplies jobs for a large number of people (3 500 approximately, A Kaye pers. com.).

The chokka squid, like most other exploited cephalopods in the world, seems to be a short-lived species (Augustyn *et al.* 1994). This fact places very special challenges on managing such resources optimally, and often expensive 'real time' approaches are required. This was mentioned as one of the key features of squid biology which bear management implications during the course of recent CIAC (Cephalopod International Advisory Council) sessions (Lipiński *et al.* 1998). The population of a short-lived species consists primarily of one or two cohorts, which means that the benefits from a fishing season hinge almost entirely on the success or failure of the annual recruitment to the stock. The earlier in the season the recruitment level is estimated, the more efficiently the resource can be utilised: the fishing industry would be able to take a bigger catch when recruitment is known to be high and a more conservative smaller catch when recruitment is low. When management implications of the squid biology were discussed at CIAC 97 (Lipiński *et al.* 1998), a key factor noted was that the only manner in which catch levels in one year affect abundance the next is through the stock-recruitment relationship. In other words, catches should be such that they would allow enough spawners to survive so as not to jeopardise the next year's recruitment, i.e. to prevent recruitment overfishing. Unfortunately there is very little empirical knowledge on the features of this relationship in the case of the chokka squid. In the case of other exploited cephalopod species, the only information available comes from a schematic stock-recruitment

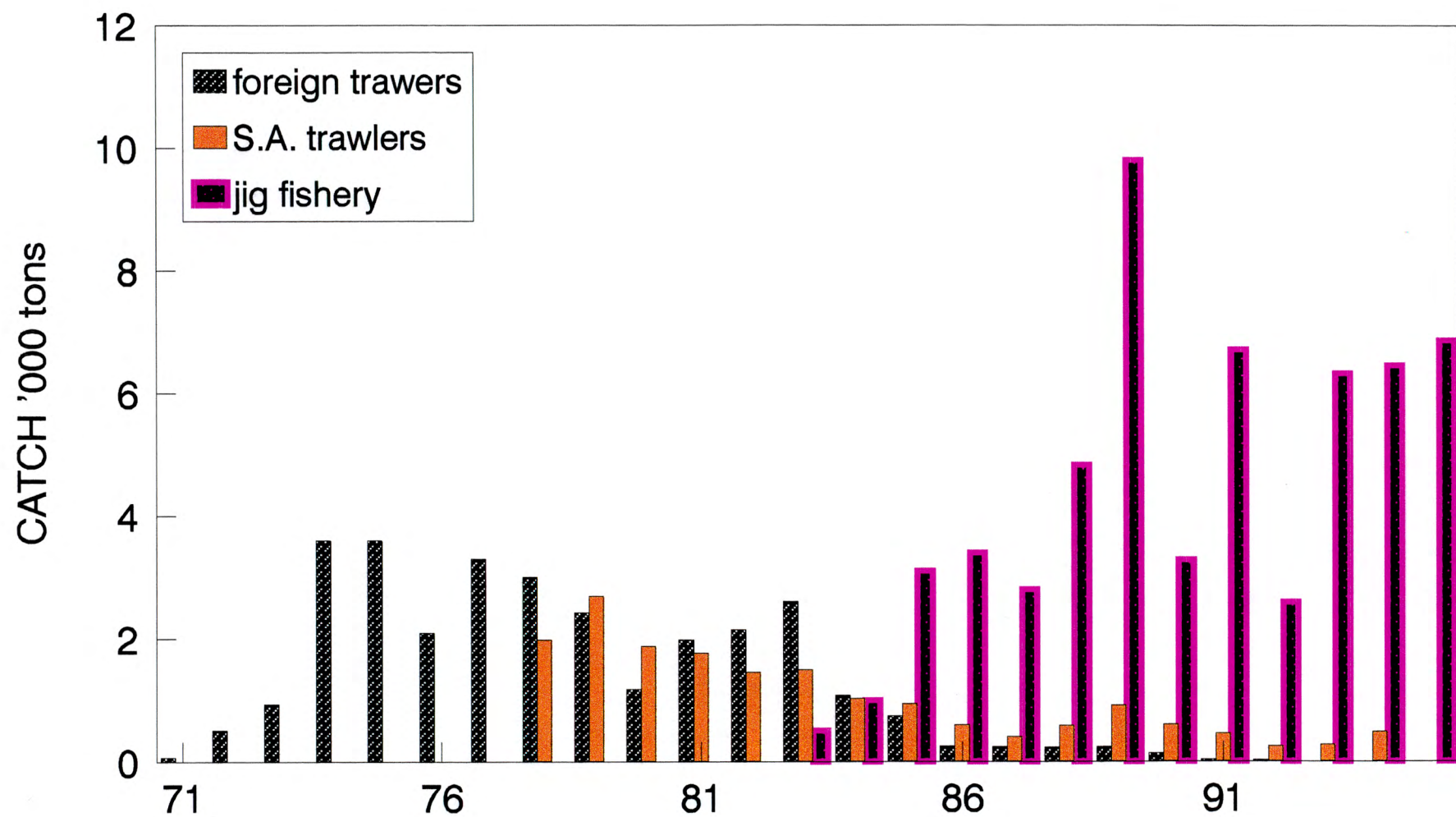


fig. 1.2: chokka annual landings from 1971 to 1995, by the trawl fishery, South African and foreign trawlers, and by the jig fishery.

relationship that was developed for *Illex argentinus* (Beddington *et al.* 1990) and used as a basis for management and also a series of stock-recruitment plots for *Illex argentinus* by Basson *et al.* (1996) from various assessment models results and data for the years 1987-1991.

Chokka is found inshore in large spawning aggregations that are easily detectable by fishermen. The position of some of these aggregations has been mapped during the course of an investigation undertaken by Sauer *et al.* (1992) along the inshore area of the Eastern Cape. The location of the spawning sites has also been identified from the occurrence of eggs in trawl nets during demersal scientific surveys (Roberts and Sauer 1994). These sites seem to be fairly stable during a season and abandoned only when weather conditions become unfavourable for spawning. Such features make chokka very vulnerable to fishing while spawning, and this fact needs to be taken into consideration when making management recommendations related to the stock.

Jigging operations seem to have a well-defined selectivity pattern, according to the results from an experiment undertaken by Lipiński (1994). In this study, a single school of chokka was sampled by means of jigs, midwater trawl with a 12-mm liner and a purse seine with a mesh size of 12 mm. Under the assumption that the purse-seine catch was representative of the school as a whole, comparison of the length frequency plots indicated that the catches obtained from jigging were highly selective. In particular, these analyses revealed that squid larger than 28 cm were over-represented, while sizes less than 26 cm were under-represented in the jig catches.

Management of the fishery has been based on the scientific advice provided by the Sea Fisheries Research Institute (SFRI) and has focused on controlling the effort deployed. Chokka has been used by line-fishermen as bait since the early days of angling activity in South Africa. Later, chokka were caught in trawling operations as a by-catch by the local fleet and as a directed catch by the Japanese and Taiwanese fleets (Augustyn 1989). The local fleet started to target on chokka, known as "calamari" internationally, in the early 1980s as prices increased in the market. By

then the foreign fleets' effort had been reduced in South African waters. The first management measure undertaken for the newly established jig fishery was to put a ceiling on the number of permits issued. This process took place between 1986 and 1988 and resulted in a reduction of the number of active boats from 560 to 235 (Augustyn *et al.* 1992). Later, a closed period of about one month was enforced during the peak of the spawning season in an attempt to ensure that at least a substantial portion of the spawning process would take place undisturbed by fishing. A similar rationale was used to justify the permanent closure of the Tsitsikamma Coastal National Park (which falls within the area of chokka distribution, Figure 1.1) to commercial fishing. These control measures, although they have been refined during the course of more recent years, are still in place. Other measures to control effort escalation by stopping vessels from upgrading have been attempted, but faced strong opposition at the time of implementation. For a more detailed history of chokka management in South Africa the reader is referred to Section 1.4.

Although the fishery has not developed uncontrolled and serious attempts have been made to manage it on a scientific basis (Augustyn *et al.* 1992), the approach taken has generally been qualitative. Due to the considerable uncertainties in the fishery, management has necessarily been conservative. Quantitative stock assessment provides the necessary tools to evaluate the short- and long-term impact of alternative management approaches on the fishery. The present thesis addresses the assessment of the stock using quantitative approaches and makes management recommendations directed towards improved utilisation of this valuable resource.

Throughout this thesis, reference is made to seasons. It must be stressed that the seasons correspond to the southern hemisphere.

1.1.2 Review of stock assessments of other cephalopod resources

Pierce and Guerra (1994) review existing knowledge on population biology and methodology applied to exploit and regulate cephalopod fisheries. The type of data required for this purpose, as well as some of the problems related to data

collection are considered. The paper focuses on assessment methods by examining the range of approaches taken and discussing examples of their application to cephalopod fisheries. They distinguish two general categories of assessment (in-season and post-season) but, although the merits of in-season assessment for cephalopods, i.e. close assessment of the status of the resource as the fishing season progresses, are often raised in their review, the authors conclude that this classification is related to the way the methods are applied more than to the methods themselves.

The main assessment methods reviewed by Pierce and Guerra (1994) are:

1. biomass dynamic models,
2. cohort analysis,
3. length-based models and
4. depletion estimates of stock size, which basically refer to the application of methods based on the modified Leslie-De Lury analysis (Rosenberg *et al.* 1990, Brodziak and Rosenberg 1993).

Pierce and Guerra (1994) maintain that some of the assumptions made by the first three model approaches listed do not apply to cephalopods. For example, those authors argue that the assumption made by traditional production models that density-dependent effects dominate population dynamics, does not apply to cephalopods, where recruitment may depend more on environmental conditions. However, if environmental effects on recruitment are strong, this simply means that process errors in a production model are larger than normal. It does not invalidate the appraisal itself, merely indicates that different estimation techniques may be more appropriate.

Pierce and Guerra (1994) raise the argument of whether cephalopods can be assessed by means of methods designed for fin-fish, and they conclude that such methods could be appropriate as long as the underlying models used take into account the main features of cephalopods dynamics, i.e. short life, variable growth and a weak stock-recruit relationship. Pauly (1998) in an analysis of the factors that shape organism growth, mortality, etc. suggests that in fisheries management terms cephalopods are very similar to short-lived fish. The behaviour of their populations to

fisheries exploitation may therefore best be understood in the same context as general fisheries models, rather than considering that cephalopods in any way contribute a special case due to their phylogeny.

An assessment of *Loligo duvauceli* exploited off Mangalore (Sunilkumar Mohamed 1996), south-west India, was undertaken applying yield-per-recruit methods (Beverton and Holt 1957) with estimates of the parameters being obtained by means of the methods of Cushing (1975), Pauly (1980, 1984) and Srinath (1991). The results indicate that fishing pressure is excessive and that the stock has been reduced to a level below that yielding MSY as a result. However, care should be taken when interpreting these results in that, particularly in the case of loliginid squid, growth is highly variable and age-length relationships assumed in that study are consequently weak (Anon. 1993, as cited by Pierce and Guerra 1994).

A first step towards assessment of the small-scale squid hand-jig fishery off the north-western Iberian Peninsula is presented in a paper by Simon *et al.* (1996). The authors apply a method developed by Gomez-Muñoz (1990) to estimate total catch and catch per unit effort. This method can only be seen as a way of obtaining data which are not available otherwise in this type of fishery, and is a pre-requisite for a formal assessment.

The paper of Basson *et al.* (1996) considers assessment techniques for migratory annual squid stocks using the *Illex argentinus* fishery in the south-west Atlantic as an example. The aims of the paper are twofold: first, to extend the assessment methodology developed by Rosenberg *et al.* (1990) to estimate total stock size; secondly, to apply the methodology to historic data, with a view to determining a value for the threshold at which recruitment becomes dependent on the spawning biomass level. The assessment is based on the Leslie-De Lury model with some modifications to the approach taken by Rosenberg *et al.* (1990) to account for the lack of data on catches taken outside the FICZ (Falkland Islands Interim Conservation and Management Zone), and for the lack of knowledge about mixing of squid between the FICZ and the "out of zone" area.

A reference to the assessment techniques used for *Loligo gahi* off the Falkland Islands is provided by Agnew *et al.* 1998. That fishery is assessed using a modified Leslie-DeLury model (Rosenberg *et al.* 1990, Basson *et al.* 1996). The author indicates that one of the two main assumptions made by the model which relates to population closure often breaks down in the case of *Loligo*. In order to circumvent this problem, *ad hoc* corrections for immigration have been estimated in some cases (Tingley *et al.* 1990, 1992). In others, averaged estimates of key parameters such as catchability have been derived from data for previous seasons to provide management advice.

1.1.3. Management approaches taken in other squid fisheries

The management objectives pertinent to cephalopod fisheries fall into the general classification put forward by Hilborn and Walters (1992): biological, economic, recreational and social. A traditional biological objective has been maximum sustainable yield (MSY), but cephalopod stocks simply vary too much for it to be feasible to identify and estimate a true MSY. Further, MSY has been discarded as a goal for fisheries management for some time now for a variety of technical and practical difficulties associated with its use as a target reference point (Caddy and Mahon 1995). Optimal utilisation (Augustyn *et al.* 1992) appears to be a concept which would accommodate variations in stock size as well as some vague economic considerations. However, in most fisheries objectives are not clearly specified even though formal objectives are required for most types of optimisation (Hilborn and Walters 1992).

Much fishing for cephalopods takes place on pre-breeding stocks (Pierce and Guerra 1994), and therefore those authors stress the need for careful management of those short-lived species for which recruitment failure attributable to overfishing on the current year's stock could be catastrophic (Rosenberg *et al.* 1990). In the case of annual species caught before spawning takes place, management should aim at ensuring sufficient survival of the spawners in order not to jeopardise recruitment the

following year. This last principle requires good knowledge of the stock-recruit relationship or, if such knowledge does not exist, a conservative attitude when it comes to management of the resource is needed.

Beddington *et al.* (1990), when referring to the provision of management advice for the squid species (*Illex argentinus* and *Loligo gahi*) around the Falkland Islands, argue that there are two ways to address the management target of safe spawner escapement:

1. To maintain the spawner escapement above the level where the probability of poor recruitment begins to increase appreciably, e. g. fixed escapement;
2. To allow a constant proportional escapement in each season, which means a constant harvest rate.

The authors argue that the second strategy is more suitable in cases when the stock size is unknown until the season has progressed far enough for estimates to be made on the basis of fishery data. Long-term yields from the fishery can then be maximised by within-season monitoring and mid-season adjustments, which would take into account the current year-class strength as well as changes in fishing power of the fleet. For the fishery around the Falklands, a management target of 40% proportional escapement has been used, which follows convention in other major squid fisheries (Caddy 1983, Beddington *et al.* 1990)

Among the most commonly used tactical tools (gear restrictions, season length, gear limitations, effort limits and annual catch quotas) effort limitation is, according to Beddington *et al.* (1990), the most efficient means to managing squid fisheries. This approach is followed to control both cephalopod fisheries in the Falkland Islands. In the case of the major fishery exploiting *Illex* throughout its distributional range south of 45°S (Basson *et al.* 1996), a rapid increase in effort in the mid-1980s led to the creation of the Falkland Islands Interim Conservation and Management Zone (FICZ) in October 1986. Within the FICZ, effort is controlled by issuing a limited number of licences that allow fishing for a fixed period of time and by limiting the duration of the fishing season. A detailed description of the

management approach taken is given in Beddington *et al.* (1990). The stock is also exploited in unregulated waters to the north of the conservation zone. As a result, good management of the resource within Falkland Islands waters may be partially undermined by fishing on the high seas. Although Basson *et al.* (1996) have extended the assessment to the area outside the FICZ, further work seems to be needed in order to regulate fishing effort over the entire area of operation of the fishery. The fishery for *Loligo* within the FICZ is described by Agnew *et al.* 1998. The number of vessels licensed is fixed before the season starts on the basis of an assessment of the fishery undertaken the previous year. As for *Illex*, in-season information could lead to an early closure of the season, but this event has not yet taken place even when escapement has apparently declined below this level (Agnew *et al.* 1998). Effort control is also the tactic used in harvesting the South African chokka and a detailed description of how it operates is given in sections 1.4 and 1.5 of this Chapter.

An important commercial fishery exists in the northwest Atlantic, targeting on the long-finned squid *Loligo pealei*. At present management of the stock is based on a level of total allowable catch that cannot be exceeded and on an overfishing definition (Brodziak and Macy 1996). On the basis of their results from a growth study on *L. pealei* and on estimates of maximum yield per recruit, these authors estimate an interim level of annual sustainable yield, which is less optimistic than the levels estimated previously. They also advocate the application of a constant harvest-rate strategy that includes a proportional escapement target, as an alternative to the existing quota-based harvesting strategy. The access to the fishery is limited and a special permit is required for vessels to harvest, possess or land more than 2 500 pounds of *Loligo*. These permits are allocated to vessels on the basis of historical performance (J. K. T. Brodziak pers. comm.).

General aspects of the management approaches taken in the Japanese *Todarodes* and the fishery for *Loligo forbesi* in the United Kingdom, are outlined in the review of Pierce and Guerra (1994). Apparently, the former has not been managed for effective utilisation of fishery resources and fishing effort has consistently exceeded the calculated optimum levels. *Loligo forbesi* is a by-catch of a multispecies

fishery, primarily directed at whitefish. Although there seems to be a case for managing this squid fishery, management options seem to be limited by the nature of the fishery and the procedures currently in place to regulate whitefish fisheries.

1.1.4. Socio-political context. Background to history of utilisation and current pressures, with focus on the jigging fishery

The general elections that took place in South Africa in 1994 marked the onset of a new democratic era for the country. However, the transformation being undergone by most institutions and sectors of the society is a complex and generally slow process. With regard to fisheries, the Reconstruction and Development Programme (RDP) states that: "Marine resources must be managed and controlled for the benefit of all South Africans, especially those communities whose livelihood depends on resources from the sea. The fishing stock must be managed in a way that promotes sustainable yield.... The democratic government must assist people to have access to these resources. Legislative measures must be introduced to establish democratic structures for management of sea resources (African National Congress 1994)".

Cochrane and Payne (1998), in a paper that refers to the debate surrounding developing fisheries policy for South Africa, identify the following key issues in the above statement of the RDP: the need for management and control; definition of the beneficiaries; sustainable utilisation; clarification of access to the resources; and the nature of the management structures. Of these issues the one related to access rights to the national marine resources is obviously the most controversial. There are strong perceptions that exploitation is still in the hands of few 'white' dominated companies and the Government's promises to broaden this access by facilitating the entry to the fisheries of previously disadvantaged individuals and communities has created expectations that have translated into a flood of demands for quotas and fishing permits.

In order to kick-start the process of transformation in the area of fisheries, the

Government appointed a Fisheries Policy Development Committee (FPDC) in October 1994. The FPDC completed its work in June 1996 and submitted a draft fisheries policy to the Minister. However, this draft did not address even the broad principles of how to allocate access rights in the future (Cochrane and Payne 1998). Consequently, the process of evolving an acceptable policy and new Sea Fisheries Act was put back in the hands of the Chief Director of Sea Fisheries, who appointed three task teams, one to drive the overall policy, one (to report to the first) to address the access rights issue, and a legal team to redraft the Act (through a Bill) and its subsequent regulations. The White Paper on Marine Fisheries (Anon. 1997) appeared in June 1997 and the draft Marine Living Resources Bill in November of the same year. At the time of writing, the Bill is before Parliament and the hope is that it will be promulgated by mid-1998. Whatever happens, it is critical that progress towards stability is made, so reducing uncertainty in the fishing industry.

The squid jigging fishery has not been immune to these winds of change. A Task Group, consisting of members of the Department of Sea Fisheries and members of the Squid Industry, was created at the end of 1997, to consider and put forward alternatives to address the Minister's request for broadening access to this resource. This process should take place in the spirit of the RDP of ensuring sustainable utilization and for the benefit of all South Africans, specially the ones whose livelihoods depend primarily on fishing. A good understanding of the present structure of the squid industry, as well as of the political and economic forces that have shaped it, becomes crucial in a process that may need to impose some changes, but should never distort or create conditions for an economic collapse of the existing industry.

An interview with Mr Richard Ball, an entrepreneur active in the squid industry since its inception and chairman of the South African Squid Management Industry Association (S.A.S.M.I.A.) for a number of years, was carried out to gain insight into the processes that led to the establishment of the present squid industry. A summary of the main arguments presented and interpretations drawn from the interview is given below:

“The first squid concentrations seem to have been found in the same areas heavily exploited today: the Humansdorp and Jeffrey's Bay area (see Fig. 1.1). In early days there were informal fishermen: surfers, etc. and fishermen supplementing their incomes from linefishing who, when squid arrived, moved into the industry very quickly. Initial activities were relatively unpoliced and disorganized. Before 1985, squid were caught mostly for use as bait and very little was consumed on the local market. The change in market's perception of squid came about as a result of the export market finding our local product so welcome. In earlier years, squid were traditionally caught in large quantities especially from Kalk Bay. The species was, of course landed by the bottom trawlers in reasonably large quantities and one of the more interesting features of squid catch records over the years is to see how, as the jigged catch took off, the amount of squid landed by the trawlers dropped quite dramatically.

“Effort increased rapidly once the fishery really got going in about 1983 – 1984, and by 1985 – 1986, there was a feeling that the effort should be capped. The initiative came from both the Department and the people involved in the fishery, because they wanted to prevent additional people from gaining access to what was already perceived as a very lucrative resource. Therefore, on the basis of historical performance up to 1985, a certain number of licences were allocated. The number of licences was related to the size of the operation existing then. However, questions were asked regarding the accuracy of the declared catches.

“The Minister at the time felt very strongly that squid should remain a small man's fishery and actively discouraged the involvement of larger industry. Accordingly, immediately after those initial years, the industry remained an essentially fragmented, “one man - one boat” type. From the 1990s, a number of vessels changed their operations from the traditional beach landings, in which small skiboats went out daily, brought fish back to buyers on the beach and then took the fish to factories for further processing and export. A number of fishers, particularly those based in Cape Town, found that they could obtain better prices by installing freezing facilities in their boats. Initially, existing boats were converted, but later new freezer boats were

built.

The criterion for receiving a permit was a minimum catch specified for the period concerned, expressed as number of tons per boat. There were two types of permits allocated: restricted and unrestricted. The restricted permits were allocated to people that had traditionally caught squid in small quantities, usually for bait. Today, the remnant of that remains, and restricted permits still exist for fishers based in Struis Bay, Port Alfred, Kalk Bay and a few other areas. When the permits were allocated, there was a period set aside for people to object, and there were those who believed that they should have received more allocation in terms of men on board than they actually did, or that they had been excluded for one reason or the other. The question is whether the reduction of the fleet or the filtration procedure was fair or not, *post facto*. Of course, many people maintain strongly that they were disadvantaged for some reason or other, but analysis of what went on at the time will probably show that it was a reasonably fair exercise. Fishermen tend to be vocal individuals, but the general consensus is that, while the process may not have been perfect, it was fair.

“As far as freezer boats are concerned, one of their prime markets, particularly in the early stages of the fishery, was the Italian market, where South African product was sold in many cases as “fresh” into the local Italian markets. Accordingly, the Italian market required fish of chocolate colour. When squid are caught, they are essentially translucent. They then go brown because the colour cells retain their ability to provide marking but, after a few hours, depending on the heat, the way the squid are handled and whether in fact they come into contact with freshwater, they tend to become white. What the Italian market was looking for particularly was chocolate colour squid, and the best squid of that type could be produced by the freezer boats, which started enjoying a premium price over the land-frozen product and, more importantly were able to move their product more successfully in weaker markets.

“The current composition of the squid industry has a great deal to do with the way in which the market developed, and with the fact that, over the last few years, many boats have installed freezing facilities. All this has meant that the capital

requirement for squid fishing has changed quite dramatically. Today, a skiboat, without licences, would cost something of the order of R100 – R150 thousand, with the engines. Even a comparatively small, perhaps 18 – 20 m freezer would probably cost of the order of a R1.5 million. Therefore, there has been a dramatic change in the capital required to continue in the fishery and this has meant that many of the less successful fishermen have been shaken out. That includes those not able to look after their finances adequately. Also the larger companies have assisted by providing loans and there has been an aggregation of permits or of operators to the point where today, squid fishing is a less fragmented business than it was initially. Moreover, in the early days, the quality requirements were comparatively unimportant, but today, as a result of the strenuous effort of both industry and the South African Bureau of Standards, and at the insistence of the market, only those operators that continue to provide a reliably excellent product are able to stay in the business. Once again, the trend over the last three or four years has been to move away from land-processing because you cannot produce the chocolate coloured squid. The effect of this has been that many of the shore factories in Humansdorp and elsewhere have closed down. It has meant that virtually all the successful fishermen have moved towards owning freezer vessels, meaning a large increase in capital requirements. As a result, there has also been an increase in the vulnerability of the industry to changes in viability. Whereas previously, a skiboat, could easily be moved up and down the coast, perhaps to target linefish, so maintaining the fishing business reasonably easily. However, a boat costing R1.5 million, plus the value of the permits which perhaps might add another R600 thousand (for 20 fishermen) becomes an investment of more than R2 million. If there is a fair amount of bank or other finance involved, something of the order of 70 tons of squid per year is currently required before profit can be made from such operations. Earlier, with a skiboat operation, the break-even point was much lower.

“The current level of representation of formerly disadvantaged persons is not easy to determine. An analysis of how the industry is made up today to find out how entrepreneurs survived would be required. In 1987 – 1988, there were quite a number of formerly disadvantaged fishermen involved in the business. For one reason or another, many of them had sold out of the business 5 years later, and 10 years later

there are, in fact, a relatively modest proportion of the original pioneers still involved. Perhaps, however, no more than 60 or 70% of the people in the business today were in the business at its outset.

"A process of restructuring, involving some broadening of participation in the industry is currently taking place. There is definitely merit in giving those with restricted permits first permission because they are *bona fide* fishermen. If they maintain their restricted permits and there is some performance against them, then they certainly deserve preferential treatment. However, they may not necessarily be classified as previously disadvantaged, although many of them are.

"The industry is now relatively mature and, for newcomers to enter, it will be difficult for them to do so at the skiboat level because the skiboat-caught squid are not particularly highly prized in the market. There is still a place for this, but most fishermen have moved up to the freezer boats for good economic reasons. That means that new entrants will no longer be able to enter an early growth phase of the fishery. They would have to enter with major capital investment. Time will tell whether they can service that investment, but it is certain that there is no other industry in the world like fishing which discriminates between people who do not perform and those who do. Simply providing finance for and giving assets to people who are unable to bring in the fish, is going to be potentially a very demanding exercise for the money-supplier.

"The squid business at the moment is vulnerable for a number of reasons. First, recent catch rates have given fishermen major cause for concern, particularly because many have just upgraded to more expensive fishing units, put up cold stores and improved their infrastructure. At exactly the same time, there has been a downturn in catches. Secondly, on the marketing side there are commercial stocks of squid in India and China that were previously caught only by small boats, so export markets were closed for those countries. Now, bigger operators with more sophisticated units are being allowed into the fishery and both countries are becoming major competitors to South African interests. Catches are improving in quality, and

infrastructure is being developed away from a labour-intensive to a well-controlled and managed fishing business. As a result squid are landed at about 70% of the South African cost. Operational costs in the East are lower, so there is a major market competitor to South Africa at the same time that the resource is under stress. To conclude, the South African squid industry is much less attractive now than it was before, so fewer people will be able or willing to invest in it.

“It would be uneconomic for newcomers to try to market chokka locally. A product which gets US\$ 5 - 6 per kg on the export market, when *Illex*, which is what the restaurant-trade, local market wants, can be imported at just over US\$ 1 per kg, i.e. 20% of the price, is not a viable proposition locally. Much of what is consumed in South Africa today is imported because it is cheaper and high-quality *Loligo* has limited appeal. Therefore it would be inappropriate to take an expensive squid with export potential and force it onto the local market. It may be politically correct, but economically it does not make sense. “

1.1.5. Current management approach for the chokka squid in South Africa

A list of the management measures taken since the jig fishery started in the early 1980s, as well as the latest developments that have taken place in the fishery up to 1992, were provided by Augustyn *et al.* (1992). This list has been updated herein to date (Augustyn and Roel in press) and the contents follow:

- 1985/86, chokka permits were given to fishermen that had developed a catch record over the first two years of the fishery,
- 1986/87, a public bag limit of 20 squid/person/day was set,
 - later, the number of men per vessel was regulated,
 - purse-seining of chokka was banned,
- 1988, a closed season of initially four weeks in November was implemented,
- 1993, a variable closed season of 3 – 5 weeks was instituted. The length of the closed season was determined on the basis of the results from the South

Coast spring survey and the quantity of chokka caught in the first seven months of the year,

- 1997, a closed season of fixed duration, four weeks, was reinstated, applying also to the recreational fishermen.

The squid fishery is undergoing a process of restructuring in response to the pressures to allow access to previously disadvantaged fishermen, as explained in more detail in Section 1.4. To initiate the process of restructuring, advice was solicited from scientists. An overview of the current approach taken to assess the resource and some management recommendations were provided by the current author as part of the Institute's advice; this information is summarized below.

The biological and economic gains provided by the current closed season are small, consistent with approximately a 9% reduction in annual effort. However, decisions on the desirability or otherwise of the closed season should not be taken without consideration of the desirable effort level in the fishery as a whole.

Advice on an appropriate level of effort for the fishery is difficult to give for two reasons:

1. Although some results indicate that the current level of effort is below that which would lead to a maximum yield, the estimates on which those results are based are not very precisely determined and therefore need to be interpreted with caution;
2. Risk-related statistics (high for the base case assumptions of these analyses) are very sensitive to the assumptions made in the assessment model.

At a recent international workshop on cephalopod fisheries (CIAC'97) held in Cape Town, it became clear that very few fisheries of this nature around the world are managed by means of catch limitation, but rather that the fishing effort is being controlled (Lipiński *et al.* 1998). The primary reason for this is that establishing a reasonable quota is extremely difficult in the case of short-lived organisms such as

squid, because the total biomass is highly variable from one year to the next. As a result, management could be faced with two equally unsatisfactory options when setting a TAC:

1. a conservative TAC is set and the resource is protected but often underutilized;
2. a more risk-prone approach is taken, but the resource could be depleted if unfavourable conditions for recruitment take place in successive years.

Alternatively, when effort is fixed, the same proportion of the stock will be harvested every year, with “good years” being taken advantage of by the fishing industry, and the necessary protection being provided to the resource in years when the biomass is low. Another advantage of effort control is that misreporting of catch is not a serious factor in any assessment, as there is little or no incentive for the fishers to provide incorrect catch statistics. However, there are concerns related to the implementation of fishing effort limitations and they are related to:

- difficulties in monitoring changes in effective effort, which tends to escalate with time as a result of efficiency increases; and
- costs of enforcing the regulations, particularly those related to the number of men on board each vessel.

On the other hand, if catch limitations were to be implemented, similar problems could arise, because the need to regulate the building of capacity would still persist.

It has therefore been recommended that effort control continue to be the primary management tool for chokka squid. Considering the above statements, the implementation of measures to allow new entrants into the fishery, which is a primary aim of South Africa’s new marine fisheries policy, will require some innovative thinking if it is to be implemented without exceeding the effort levels that ensure a sustainable fishery.

The proposed strategy to generate scientific solutions to the challenges posed by the new marine fisheries policy is to open debate on the matter, involving all

parties interested in exploitation and conservation of chokka. A first workshop took place at the start of 1998, attended by scientists involved in chokka squid stock assessment as well as members of the squid fishing industry. Important conclusions from this workshop were that this fishery should continue be regulated by means of effort control and that possible interferences in the efficiency of the fishery, such as banning night fishing, should be avoided. Options to reduce existing fishing effort were discussed.

1.2 OBJECTIVES

1.2.1 *Objectives of study: to produce a management strategy for the economically important chokka squid jigging fishery based on rigorous assessment of the stock*

The ultimate goal of this thesis is to generate a management recommendation for the chokka squid based on a rigorous quantitative assessment of the stock. This goal encompasses work in the following fields:

- data analysis (Chapters 2, 3 and 4),
- modelling approaches aimed at describing the stock and fishery dynamics (Chapters 5, 6 and 7),
- application of the general principles of fisheries management (Chapter 8).
-

1.2.2 *General description of the data available and methods used in the study*

Data. The nature of the present study requires obtaining indices of biomass, and these can be provided by catch per unit effort data, which can be related to stock abundance, and by direct estimates of the stock biomass, usually obtained by means of scientific surveys. The following data have been used for this study:

Annual commercial catches from 1971 to date

Abundance indices:

- JIG catch per unit effort (CPUE)
- TRAWL CPUE
- BIOMASS estimates from demersal scientific surveys (area swept),

consisting of two surveys per year:

South Coast autumn survey and

South Coast spring survey

The following table summarizes the features of the time-series used:

Table 1.I: Features of the time-series used

Features	JIG	TRAWL	AUTUMN S.	SPRING S.
Sample size	Large	very large	small	small
Length	1985-1995	1978-94	1988-96	1986-95
What is sampled	Spawners	entire population	juveniles and adults	adults

Methods

The dynamics of the stock and of the fishery have been modelled in order to assess the resource status and productivity. The approach taken has been of single-species, biomass-based, stochastic models. The first term refers to the facts that the dynamics of one species only is modelled and, although chokka squid is a component of a complex ecosystem, this reality is ignored under the assumption that the characteristics of the stock itself account for most of the observed variability in abundance. It is biomass-based because the stock is modelled as a whole, without taking into account its size or age structure. This approach is taken because the length frequency information available was not, at the time of writing, sufficient to estimate the length composition of the catches, which is a prerequisite to the building of size-based or age-structured fisheries models. The models developed are stochastic because they contain an element of uncertainty; in other words the model predictions are provided as distributions rather than as point estimates. Parameter and variance estimation has been done using the following methods:

- Generalized linear modelling (GLM);
- Maximum likelihood for estimation of population parameters;
- Bootstrapping to estimate confidence intervals.

The trawl CPUE data are analysed by means of Generalized Linear Modelling techniques (Kimura 1981) to estimate the year-factors related to squid abundance on the fishing grounds which coincide with the squid area of distribution. The year parameters estimated by GLM should reflect squid abundance having removed the effects of such other factors as catch position and time of the year in which the catch took place.

The model parameters are defined as a quantitative property of the system modelled, which is assumed to remain constant over some defined time-span of historical data and future predictions (Hilborn and Walters 1992). Analytical estimation was the preferred option to estimate model parameters, but when it was not feasible Maximum Likelihood estimation was used. For a general discussion of the use in stock assessment of these criteria to estimate parameters as well as for more specific literature, see Hilborn and Walters (1992).

Confidence bounds for the main model parameters estimated, as well as for some management-related quantities, are calculated by means of the bootstrap method developed by Efron (1981, 1982, and 1985). This is a computer-intensive method which uses computer-generated data to determine the amount of variation to be expected in the parameters. An in-depth study of this method in the context of fisheries assessment was made by Punt and Butterworth (1993).

A second group of methods used in the present study is directed at facilitating management decisions for this particular stock. Although fisheries scientists are not the ones who should be making choices on social or political grounds, the role of fisheries stock assessment scientists should be to provide the best possible technical support to such decisions (Hilborn and Walters 1992). In order to achieve this goal for the chokka fishery, simulation is used to investigate the effects of applying a range of

harvesting strategies and appropriate tactics. The outcomes are evaluated by comparing what are called performance statistics, which are estimated quantities useful for management purposes. Expected catches, catch variability from year to year and average growth of the resource under a particular harvesting plan are typical performance statistics. Risk evaluations, a process by which the uncertainties inherent in managing the fishery are incorporated into the advice, are performed using some of the approaches described in Smith *et al.* (1993).

1.2.3 Hypotheses tested in this study

Several hypotheses are tested in the body of the text. In relation to the assessment specifically, they are:

1. that the decline in the nominal trawl CPUE in the early 1980s reflects a real decline in the trawlers' catch rate;
2. that fishing patterns and strategies have changed over time and therefore that catch and effort data from the trawl fishery may not reflect trends in resource abundance;
3. that the closed season, as it stands at present, contributes substantially to the conservation and sustainable utilization of chokka.

If 1. is confirmed and 2. is discarded then two alternative causal hypothesis are investigated:

4. that the decline in the trawlers' catch rate is caused by the jig fishery removing the biomass that otherwise would be available to the trawl fishery;
5. that the jig fishery "disturbs" the spawning process and causes a decline in subsequent recruitment;

In the light of our limited knowledge of species dynamics, simple biomass-based models, as adapted in this thesis to this under-studied group of organisms,

provide one of the few alternative modeling approaches. The body of this thesis will attempt to show that it is possible to do this despite conflicting trends in abundance indices. Uncertainty in parameter estimates is unavoidable when trying to relate models to data and, in the case of an assessment, it translates into uncertainty in stock size and productivity. The situation is aggravated when the data are somewhat contradictory. The approach taken in this study is to make explicit the alternative hypotheses about resource status which are consistent with the data. The expected consequences of a range of management actions if each "state" happened to be true are then evaluated. The author of this thesis believes that, by presenting these alternatives clearly, she will be giving the decision-makers the tools to make informed management decisions.

CHAPTER 2

Review of current knowledge on the life cycle of chokka squid

2.1 Time-scale of the larvae, juvenile, sub-adult and adult stages

While very little research has focused on the early stages of the life cycle of chokka squid, later stages are better known as a result of several studies (Augustyn 1989, Augustyn 1990, Sauer and Lipiński 1990). The jig fishery targets spawning aggregations, whereas juveniles, sub-adults and adults are caught by trawlers, so more material for the study of those particular stages has been generated over the years. Augustyn *et al.* (1992) drew a schematic representation of the various phases of the life cycle, consisting of a) spawning, b) hatching, c) passive planktonic phase, d) active planktonic phase, e) maturation and migration. These phases can be related to the basic stages in the life cycle: larvae, juvenile, sub-adult and adult.

Paralarvae. Newly hatched chokka are referred to as paralarvae. Young paralarvae are not strong swimmers and lead a passive, planktonic existence (Augustyn *et al.* 1994). There is uncertainty regarding the duration of the planktonic phase. In *L. vulgaris vulgaris*. Active swimming takes place at an age of about 2-3 months according to Mangold-Wirz (1963), but Augustyn (1989, 1990) argues that this may happen earlier in the life of *L. vulgaris reynaudii*. The monthly geographical distribution of chokka paralarvae from Bongo net samples is presented by Augustyn *et al.* (1994). The data support the belief that the main areas of spawning and hatching are between Algoa Bay and Plettenberg Bay (see Fig. 1.1 for geographic references), and that the intensity is higher from September to December. In other months of the year the paralarvae are more dispersed and are found in smaller numbers.

Juveniles. Chokka juveniles between 20 and 80 mm mantle length (ML) are found throughout the year off the South Coast, but their abundance peaks in the southern autumn (Sauer and Augustyn pers. com.). If spawning reaches a peak during October and

November, those juveniles would be 5 - 6 months old on average. Juvenile squid eat large crustaceans and fish larvae. As they increase in size, part of the juvenile population may migrate in a westerly direction and into deeper water in search of food (Augustyn *et al.* 1994). Chokka of about 10 cm ML feed exclusively on fish and they probably follow groups of prey such as pelagic fish around the western Agulhas Bank and up the West Coast, according to Augustyn and his co-authors.

Sub-adults and adults. According to Augustyn (1989, 1990) and Sauer (1991), size at maturity is highly variable in chokka and depends on the time of the year and the geographic location. Size at maturity can vary between 90 mm and more than 290 mm ML in males, and between 100 mm and more than 180 mm ML in females (Augustyn *et al.* 1994). After examination of maturity data from the South Coast, Sauer and Augustyn (pers. com.) concluded that:

- maturation rates are faster in the east than in the central or western areas;
- maturation occurs at a smaller size in spring than in autumn;
- chokka are dispersed offshore and westwards as they grow;
- maturation takes place as the population migrates inshore and eastwards to the spawning grounds (see Fig. 1.1 for geographic references).

2.2. Duration and conditions related to spawning and hatching

Mature or spent individuals form dense spawning aggregations. Such aggregations have been examined acoustically and directly by SCUBA divers (Augustyn 1990, Sauer *et al.* 1992) in waters shallower than about 50 m. Diving under the jigging boats has confirmed that chokka are caught while actively spawning particularly, but not exclusively, during daylight (Sauer *et al.* 1992). Many of the spawning sites are located in sheltered bays along the entire Cape south coast mainly between 10 and 50 m deep (Augustyn 1990), the substratum favoured for laying the eggs being low relief rocky reefs and sandy areas (Sauer *et al.* 1992). During aerial surveys performed in summer, Sauer

and his co-authors counted at least five squid aggregations present at the same time in the area between Algoa Bay and Plettenberg Bay (see Fig. 1.1). Also, based on numerous findings of chokka egg capsules in demersal scientific surveys, Roberts and Sauer (1994) have postulated the incidence of spawning over the eastern mid-shelf (50-130 m), farther offshore than the "traditional fishing grounds". For the purpose of the present study, the area of the South Coast inshore of the 50 m depth contour is taken to represent the main chokka spawning area.

Eggs are laid in clusters made up of varying numbers of capsules or strands, with the stalks attached and embedded in the sand patches (Augustyn 1990). An individual female, often accompanied by a male, will approach the egg bed and deposit an egg strand (Sauer *et al.* 1992). The eggs take approximately 35 days to hatch at 14°C and 16 days at 21-22°C. However, in a laboratory hatching experiment, eggs did not develop normally at temperatures below 10°C or above 24°C (Augustyn *et al.* 1994). Further experiments (Oosthuisen 1998) confirm these findings, raising questions about the probability of hatching of eggs found in cooler waters, between 50 and even beyond 130 m deep, where temperatures appear to vary between 9 and 12°C (Roberts and Sauer 1994).

In a review of chokka life history and ecology for the general region of the Agulhas Bank, Augustyn *et al.* (1994) state that, although there may be some spawning year-round, there is sometimes one, but often two, peak periods in the year. Although these may also be variable, there is generally a major peak in spring, and a minor one in autumn or winter, such peaks coinciding with seasonal peaks of the jigging catches (Augustyn 1990). Histological analysis suggests that squid may be serial spawners, individual squid spawning several times during a protracted season (Sauer and Lipiński 1990, Melo and Sauer 1998).

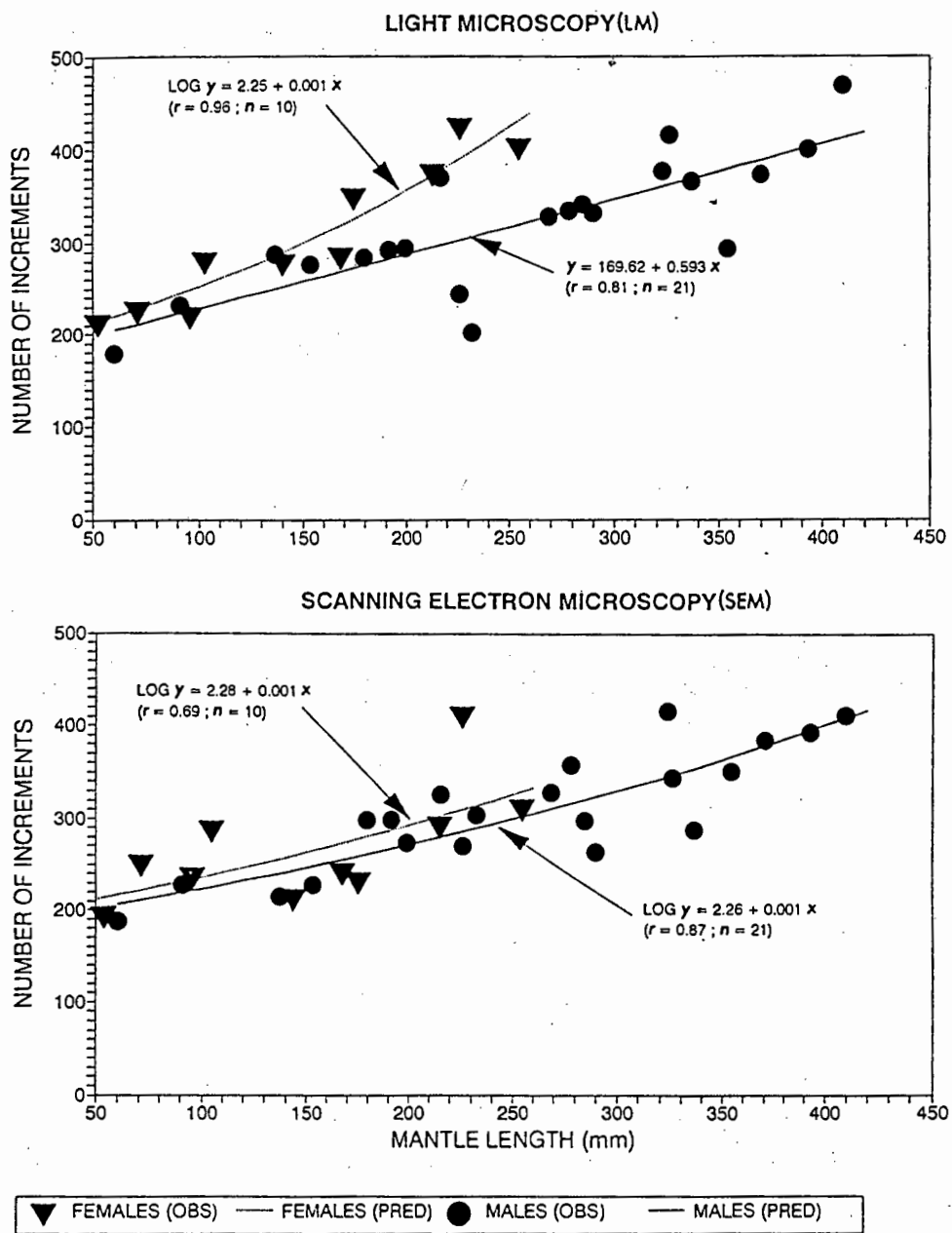


Fig. 2.1: Relationship between number of increments and mantle length for male and female squid using light microscopy and scanning electron microscopy (from Lipinski and Durholtz 1994).

2.3. Average life-span

Chokka growth was investigated by Lipiński and Durholtz (1994), who identified and counted daily increments in statoliths. Their results are sensitive to the methodology used and therefore they stress the need to apply rigorous methods to analyse statoliths. However, they present a regression between mantle length and number of increments (see Fig. 2.1) based on 31 specimens (21 males and 10 females) that suggests that large males longer than 400 mm *ML* would be about 400 days old. The interpretation of female growth is more variable, depending on the type of microscopy used for the readings; the age of the larger females of 250 mm would be somewhere between 320 and 420 days old. A validation study was undertaken by Lipiński *et al.* (1998), based on a tag-recapture method in the field. The results indicate that the increments are deposited daily in the case of chokka males in the size range 290-370 mm *ML* and that the same applies to a 273 mm *ML* female. Although it may be too early to make definitive statements regarding chokka growth, it does appear from the results mentioned above and from unpublished work (Lipiński and Durholtz pers. comm.), that, on average, the juvenile squid would be less than 200 days old, the sub-adults would be between 200 and 300 days, and the mature adults would be between 300 and 400 days old.

2.4. Spatial distribution of juveniles, sub-adults and adults

Between 1980 and 1982, three research surveys were undertaken by the Sea Fisheries Research Institute (SFRI) in collaboration with two Japanese institutes to investigate abundance and distribution of squid together with other species (Augustyn 1989). The study area covered the entire Agulhas Bank between 75 and 200 m deep. The squid caught in each trawl were classified into small, medium and large, on the basis of the dominant size-classes present in the catch. The time when the surveys took place and the size-groups considered are shown in Table I:

The distribution and size of catches (in number) of small, medium and large

chokka, as plotted by Augustyn (1989), are shown in Figures 2.2a and 2.2b. The small squid seemed to be well detected by surveys east of Cape Agulhas and inshore of the 150 m depth contour. Large numbers of medium-size squid were found west of Cape Agulhas, an area not covered by the South Coast demersal surveys referred to in the paragraphs that follow.

Table 2.I: Surveys where chokka were sampled, corresponding time of the year and size-groups

Survey	Time of the year	Size-groups
SCBS I	Nov. – Dec.	<80, 80-129, >129 mm
SCBS II	Nov. – Dec.	<120, 120-209, >209 mm
SCBS III	June	<80, 80-169, >169 mm

Augustyn (1989) examined the biomass distribution of chokka squid off the west coast of South Africa, as far south as Cape Agulhas. His main findings were:

- biomass was smaller than on the South Coast;
- the distribution of squid was generally continuous from Cape Agulhas to between Cape Point and Cape Columbine, but became more scarce farther north;
- size distributions were unimodal, and mean and modal sizes were smaller than on the South Coast;
- maturity rates and gonado-somatic indices were also much lower on the West Coast.
- In summary, his findings, together with information from the commercial fishery, indicated that chokka undergoes a process of migration between the South and West coasts, apparently to enable sub-adult squid to exploit the good foraging opportunities on the West Coast.

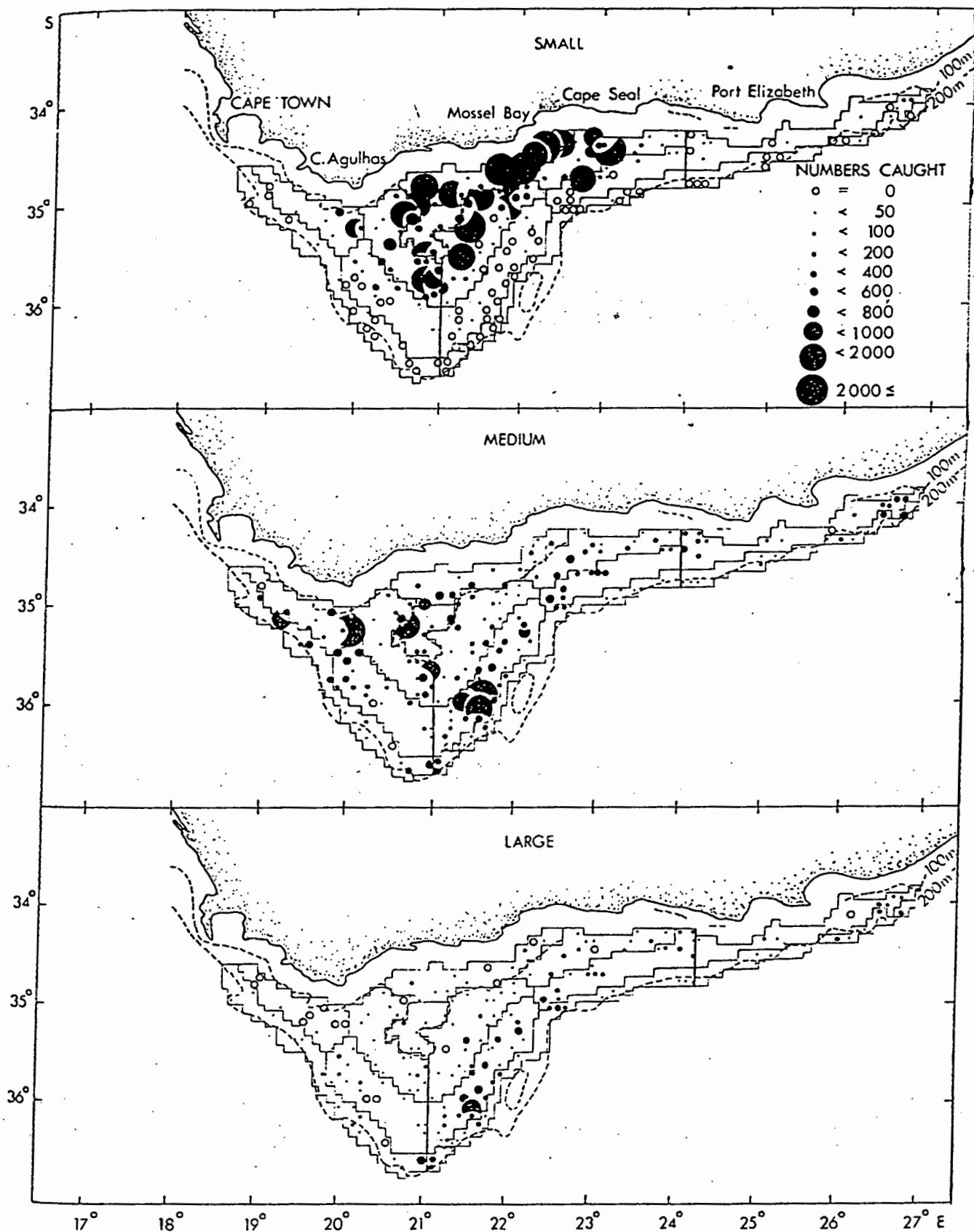


Fig. 2.2.a: Distribution and size of catches (in number) of small, medium and large size-groups of chokka during the SCBS II survey (from Augustyn 1989).

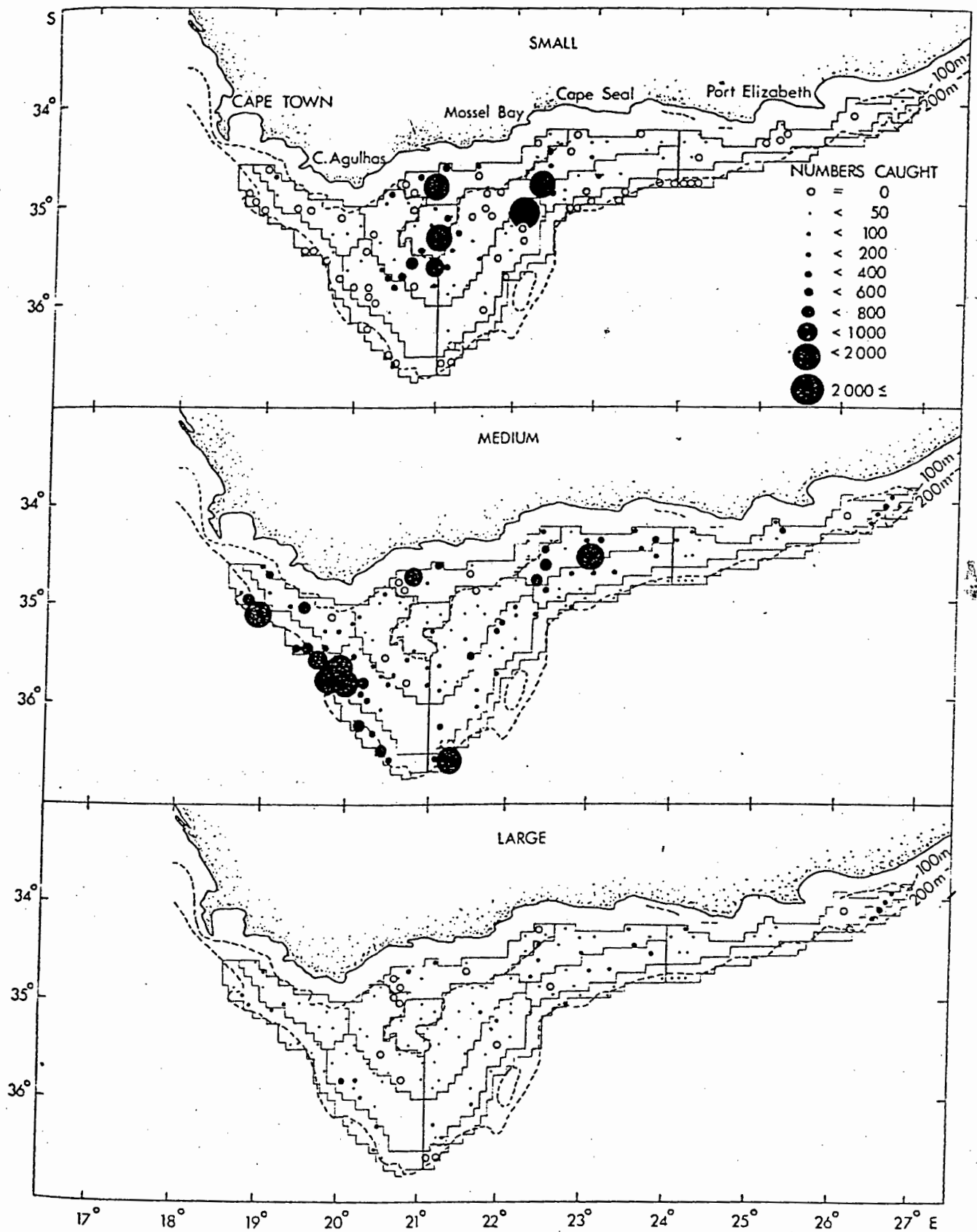


Fig. 2.2.b: Distribution and size of catches (in number) of small, medium and large size-groups of chokka during the SCBS III survey (from Augustyn 1989).

2.5. Migration cycle

A schematic representation of the migration cycle of chokka squid, giving some geographical reference points, is presented as part of a synthesis of research on *Loligo vulgaris reynaudii* by Augustyn *et al.* (1992). According to those authors, juvenile chokka move offshore from the spawning grounds in search of food, dispersing over the entire shelf. As sub-adults they will then reach either the area just offshore of their spawning grounds, or the southern and western Agulhas Bank, or reach the farthest extent of the habitat on the southern West Coast, depending on their individual circumstances of growth and maturity, and on the environmental conditions. From there, they will migrate back to the inshore South Coast as mature adults.

Sauer (1991) took length frequency samples from the jig catches on the spawning grounds between April 1988 and July 1989. The mean mantle length of the males, which are better represented than the females in the jig catches (Lipiński 1994), are plotted per month in Figure 2.3 together with the corresponding CPUE data. Between December 1988 and March 1989 the average size increased markedly, a possible interpretation being that this was the result of growth of the same cohort remaining on the spawning grounds where fishing occurred. The sharp decline in mean length taking place between June and July (1988), and between April and May, and June and July 1989 is probably the result of the influx of smaller, younger individuals to the fishing grounds. The mean lengths of males and the CPUE trends are clearly in opposite phases in the period between April and January 1989, suggesting increases in abundance or availability as a result of younger individuals migrating inshore.

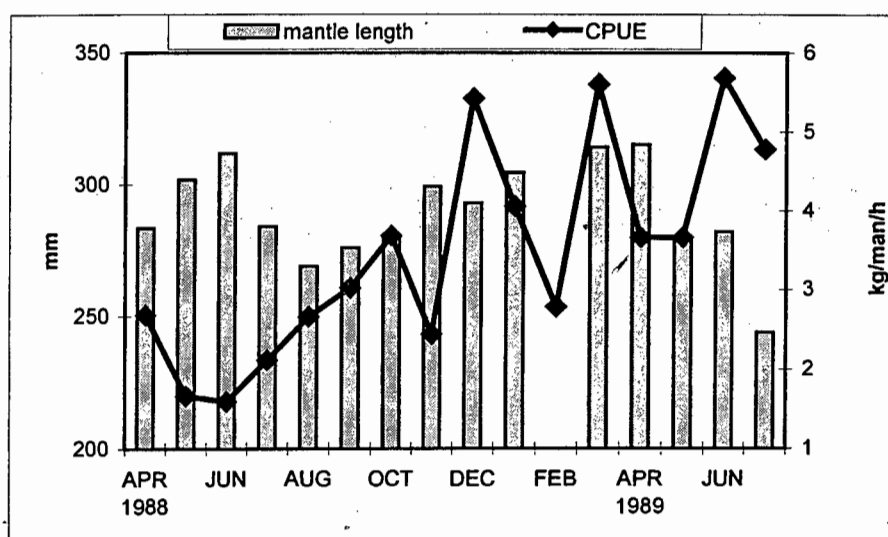


Fig. 2.3: Mean mantle length of chokka squid males from samples taken from the jig catches between April 1988 and July 1989 (from Sauer 1991), and monthly jig CPUE

A diagram summarizing the current understanding of the life cycle, reflecting the discussion above, has been presented by Augustyn and Roel (in press). A slightly modified version is shown in Figure 2.4.

2.6. Assumptions made in the assessment on chokka distribution and life-cycle.

Based on the findings regarding chokka distribution and life cycle mentioned in previous sections of this Chapter, several assumptions are made in this study when modelling the dynamics of chokka. The most important are the following:

- 1) the life-span is about 18 months;
- 2) most chokka spawning takes place between September and the end of November;
- 3) some spawning takes place year-round;
- 4) jigging fishing grounds are predominantly in waters inshore of the 50 m depth contour, coinciding with the main spawning area;
- 5) the trawlers catch mainly the sub-adults and adults;

Chokka Life Cycle

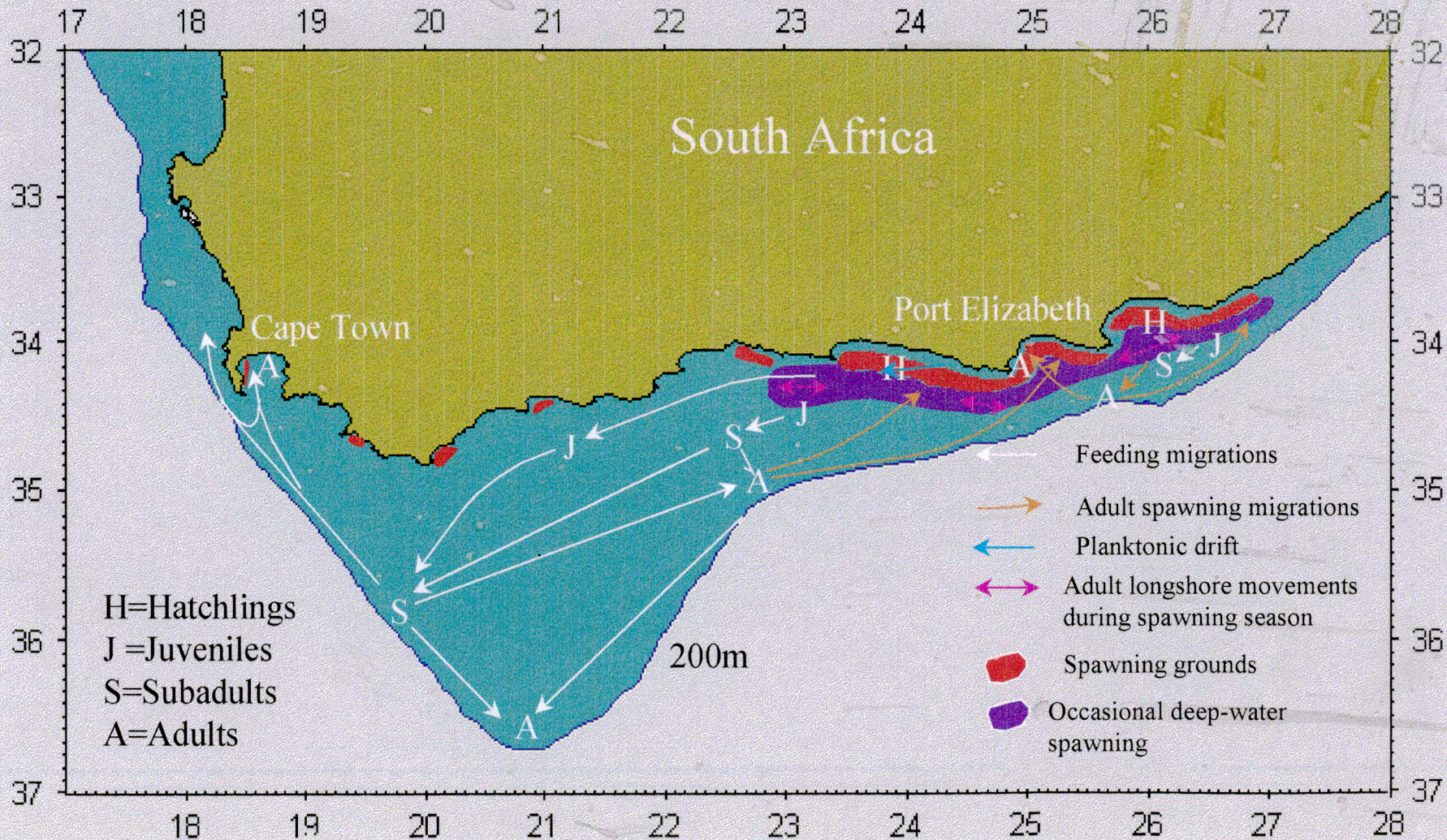


Fig. 2.4: Conceptual diagram of the life cycle of chokka squid *Loligo vulgaris reynaudii* in its main area of distribution off the South Coast of South Africa (after Augustyn and Roel 1998).

- 6) immigration to the spawning grounds takes place between May and December;

As shown above, some of the assumptions, such as the ones related to the duration of spawning and to distribution, have been well substantiated by pertinent research. Sensitivity tests to the validity of the less certain assumptions, such as the life-span, are performed later in this study.

2.7. A conceptual model of the species' population dynamics.

The conceptual model shown in this Chapter attempts to introduce processes included in the quantitative model developed in Chapter 5. An interesting conceptual model was presented by Des Clers (1997) who described the effect of trawling on *Loligo gahi* in Falkland Islands waters by comparing the stock with a carpet which was "hoovered" by the fishing vessels, which act as filter-feeders (hence "hoovers"). The dynamics of the chokka biomass on the spawning grounds are represented on Figure 2.5, modified from Payne and Crawford. (1989). Basically, the spawning biomass is shown as a pool whose level is the result of processes that contribute to an increase, and processes that deplete the existing biomass level. The processes that result in an increase are individual growth and immigration to the spawning grounds. Processes that cause depletion are natural mortality, emigration and fishing. The present study attempts to estimate the rates of these processes, and the associated uncertainty, by fitting the jigging CPUE data by means of a biomass dynamics model developed in Chapter 5 of this thesis. Other indices of abundance, the trawl by-catch CPUE and the biomass indices from the South coast demersal surveys, are also used to assess the current status of the chokka resource taking a slightly different approach from the one taken in Chapter 5. This last approach, that makes use of the four indices of abundance, is developed in Chapters 6 and 7.

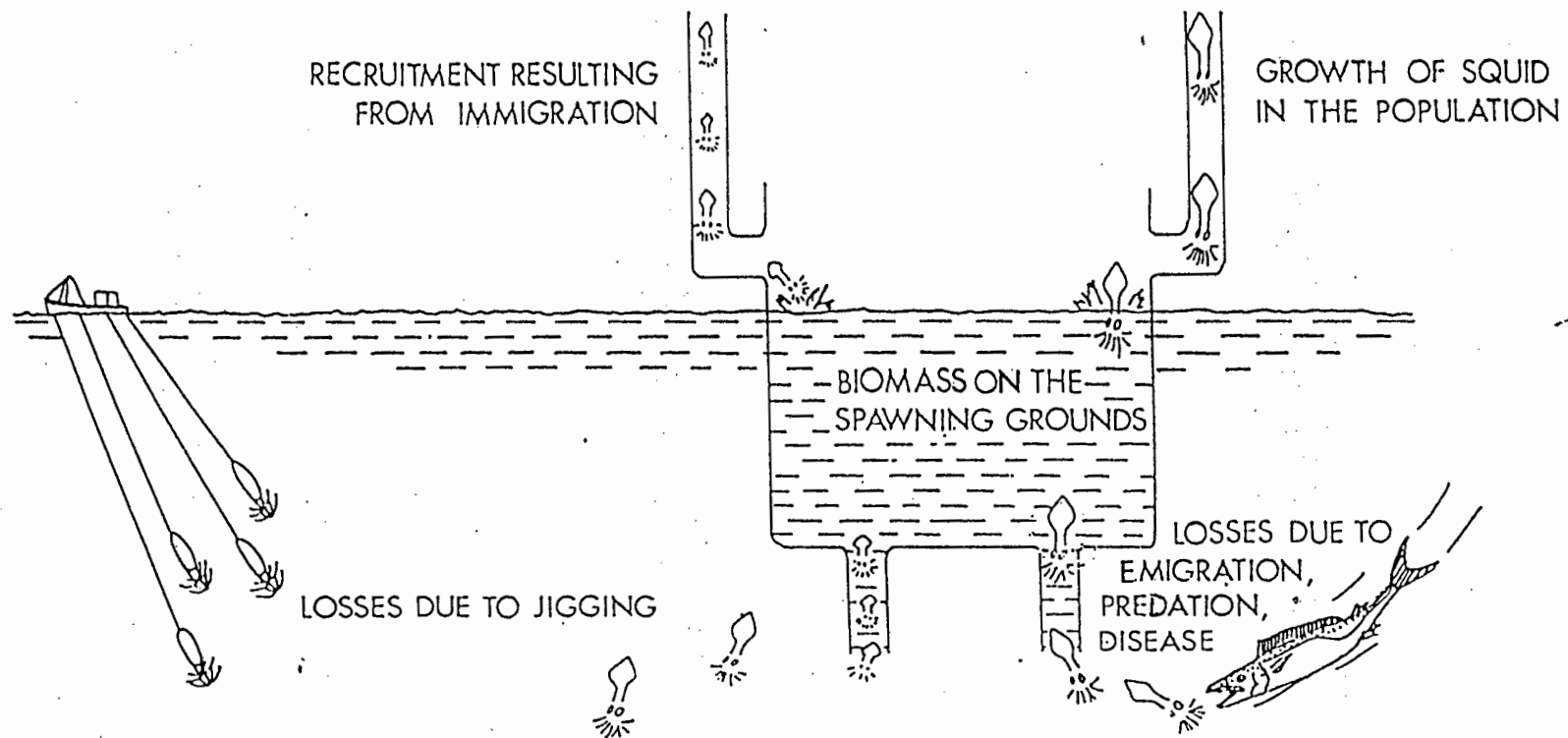


Fig. 2.5: Conceptual model of the dynamics of the chokka resource (adapted from Crawford and Payne 1989).

CHAPTER 3

Dynamics of South Africa's two chokka squid fisheries

3.1 THE DIRECTED JIGGING FISHERY

Jigging operations started in the early 1980s, but daily catch returns containing information on quantity caught, position of capture relative to the coast, hours fishing and number of men on board were provided regularly only from 1985. Catch per unit effort (JIG CPUE) used for the analysis is represented as kilogrammes caught per man per hour. These data were collected by the Sea Fisheries Research Institute (SFRI) and are stored in the Linefish Data Base. Owing to the nature of the chokka fishery, where boats would often target on linefish if chokka were not available, catch returns of both chokka and linefish have been completed daily on the same form and then submitted monthly by the skippers to the the SFRI. When both linefish and chokka were caught on a given day, the number of hours spent fishing was allocated to chokka. The rationale for this approach was that, if chokka were available, the fishermen would have targeted on them. In any case, the proportion of returns reflecting mixed catches has been relatively small.

Information on the characteristics of the boats holding licences to catch chokka commercially has been collected annually by Sea Fisheries as a condition for their registration. This information comprises vessel length and date of construction, and number of crew. By permit conditions, the number of crew is directly proportional to the vessel length. A questionnaire was addressed to permit-holders in 1989 to obtain additional information likely to influence the vessel fishing power. Questions were addressed to the boat owners regarding: hull material, whether the vessel had a deck, type of hull (mono, double or triple), type of engine (out- or in-board) and type of processing/cooling facilities.

An almost continuous process of upgrading has taken place in the chokka fleet since the first questionnaire was issued, and new vessels have replaced old ones over the years. Therefore, in order to update information on the jigging fleet, a new questionnaire was drafted and sent to boat owners together with their "permit renewal application

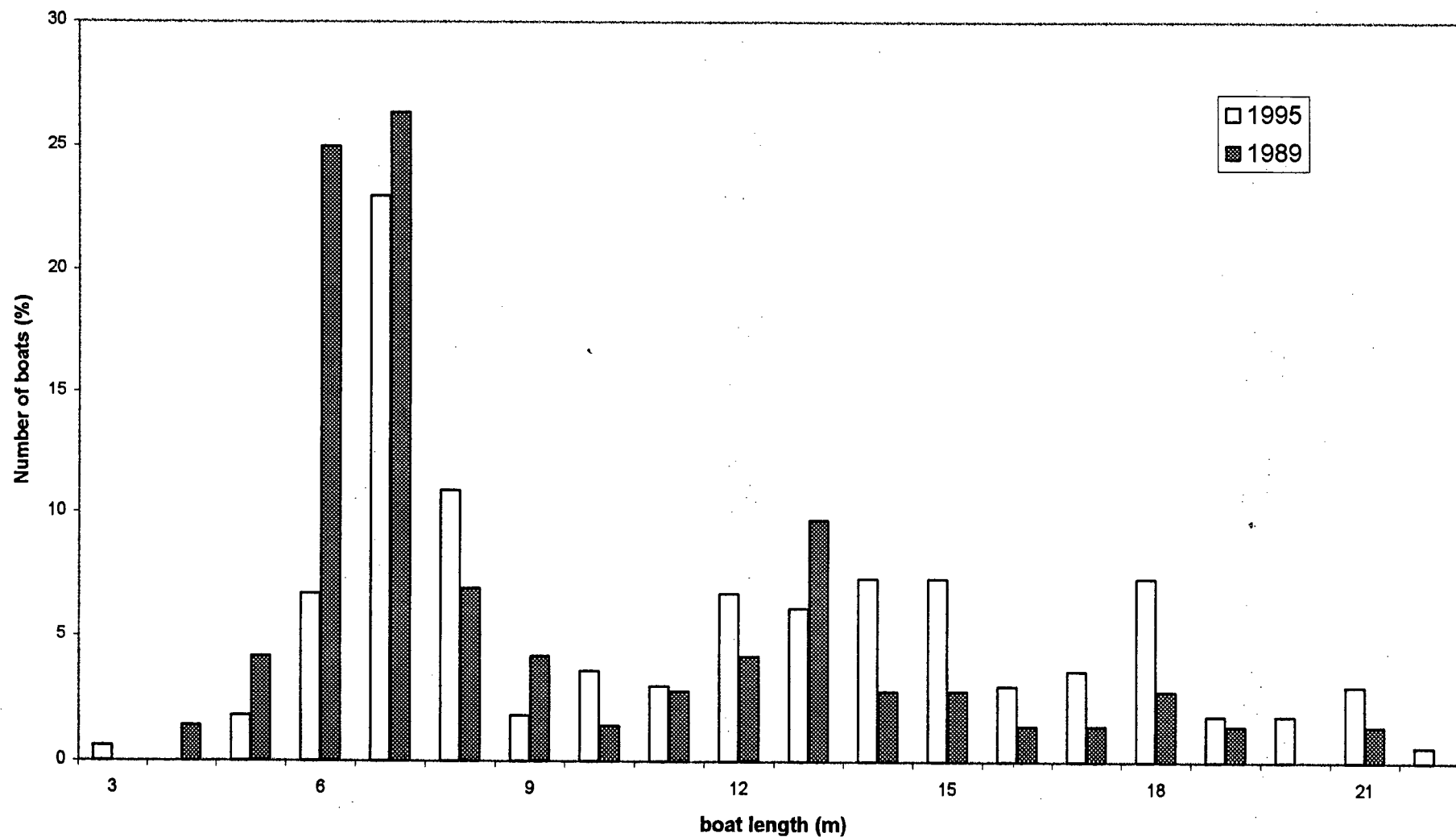


Fig. 3.1: Frequency distribution of boat lengths in the jig fleet based on the response to questionnaires addressed in 1989 (72 responses) and in 1995 (165 responses).

form" for the 1995/1996 season. An update of the information was required as a condition for permit renewal at the start of the 1996/1997 and 1997/1998 fishing seasons. The results of this process of information gathering are used in section 4.2.1, GLM analysis of jig CPUE.

3.1.1. Composition of the fishing fleet

The squid fleet has been described as extremely dynamic, and therefore it is at times almost impossible for administrators to keep track of changes in type of permit, boat conversions, etc. The boats in the fleet can be classified according to the following criteria:

- Skiboat: < 8 m long, out-board motor;
- Catamaran: > 8 m long, in-board motor, double hull;
- Deckboat: > 8 m long, in-board motor, deck, mono hull;
- Freezer: with squid-freezing facilities on board.

A list of jig fishing boats per type of licence and permit based on a questionnaire addressed to the skippers in 1996 is presented in Table 3.I. Out of 304 boats with licences to catch chokka or act as 'carrier' boats only 218 responded. However, because of incompleteness of information, only the data from 152 boats were used.

Table 3.I: Classification of the jig fishing boats according to type of licence and permit from a questionnaire addressed to the skippers. In brackets the number of boats with freezing facilities on board.

Type of licence	Fishing boat permit type		Carriers	Total
Type of permit	"C"	Restricted		
Skiboat	28 (0)	19 (0)	5	
Catamaran	26 (12)	0	2	
Deckboat	57 (56)	13 (1)	0	
Total	111	34	7	152

The chokka boats can hold either "C" licences or restricted licences. The latter, as the name indicates, restricts fishing to a certain section of the coast; the "C" licence holders can operate in any area regardless of where the boat is registered. Boats which held restricted permits were registered in Kalk Bay (18°40'E), Knysna (28°E), Mossel Bay (22°10'E) and Port Alfred (Fig. 1.1). A total of 35 carrier vessels completes the list of boats involved in directed chokka squid fishing.

The frequency distribution of boat lengths in the jigging fleet is presented in Figure 3.1, based on the information contained in the 1989 and 1995/96 questionnaires. The increase over time in the proportion of larger boats, and the corresponding decrease for smaller boats, is consistent with the general trend observed in the jigging fishery, as described by Mr R. Ball (former chairman of the Squid Management Industry Association) in Chapter 1, that resulted from the gradual move from operations involving skiboats to those involving larger freezer boats. Indeed, the proportion of boats with freezing facilities changed from <10% in 1989 to some 40% in 1995, according to the information contained in the questionnaires. At the same time, the proportion of deckboats increased from 65 to 91%.

3.1.2. Choice of units to express jigging CPUE

The relationship between CPUE, expressed as kilogrammes of chokka caught per boat and per hour, and the number of crew on board, was investigated on the basis of available data from 1985 to 1991. The mean CPUE and 95% confidence intervals are plotted in Figure 3.2 against the number of crew, grouped in 2-man intervals. Examination of the plot suggests that factors other than number of crew may be influencing the catch of boats with 1 or 2 men on board, and of boats with more than 22 men. In the case of the small boats (1 or 2 men) a combination of the skipper's ability and the likelihood that they fished only when the squid were "running" probably explains the high value. Fishing operations that involve some of the crew in packing and processing could explain why the CPUE stabilizes for boats with more than 20 crew.

In the light of this analysis, CPUE for the balance of this thesis has been calculated as kilogrammes caught per man per hour, based on data provided by boats

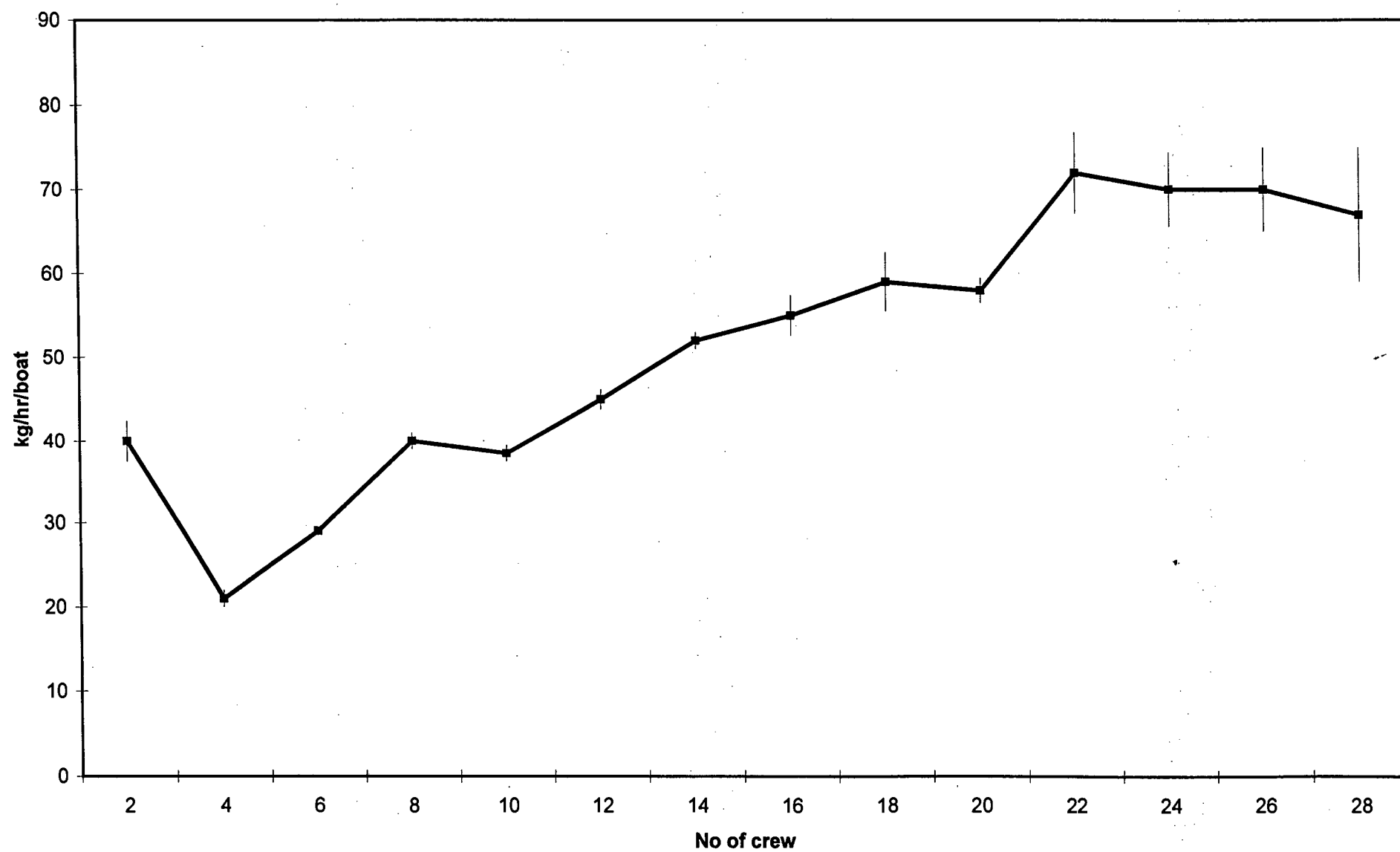


Fig. 3.2: Jig cpue (mean and 95% conf. int.) in kg per hour per boat. The boats were grouped according to number of crew. Based on data from 1985 to 1991.

with between 2 and 20 men on board. The quantities caught by boats with more than 20 crew seemed to be more related to their type of freezing activity than to the number of crew at the time the analysis was performed. A decision was therefore made to eliminate such boats from CPUE calculations. This approach is certainly not ideal, because (as already stated) the mean size of the boats has increased over time in the fishery and, as a result, so has the number eliminated from CPUE calculations. Regular data collection on boat characteristics will allow in time the application of a GLM to estimate annual abundance indices using all the data available from this fishery.

3.1.3. Temporal trends in effort

Fishing effort for a given period is calculated by dividing the corresponding catch of the whole fleet by the CPUE, calculated according to the criteria specified in 3.1.2. The effort is not calculated simply as man hours for consistency with the calculations of CPUE, which is based on the catch and effort data provided by boats with between 2 and 20 men on board. Further, this is a way of standardizing effort expressed in man-hour units, and making it independent of changes in fleet composition that has taken place over time. Despite attempts to control fishing effort in the jig fishery, the general trend from 1985 was a gradual increase until 1994 and a rapid increase thereafter (Figure 3.3). This trend is not related so much to an increase in the size of the fleet, which has remained relatively constant, but rather to the introduction of strong lights, giving the ability to fish over a 24-hour period for up to several days, as well as to the installation of freezing units on many vessels (Augustyn *et al.* 1992), allowing them to stay at sea for longer periods. An alternative explanation is that effort increased from 1985 to 1988, years during the fishery developed, and then remained relatively stable until 1994, after which it increased markedly.

Effort in the fishery is not deployed uniformly throughout the year. It peaks towards the end of the year in relation to the quantity of squid available on the spawning grounds. The average monthly effort (based on data from 1988 to 1995) is shown in Figure 3.4. The increase in effort towards the peak of the spawning season between September and November is partially confounded by the closed season of 3 – 4 weeks duration in October and/or November. After January, chokka disappear from the

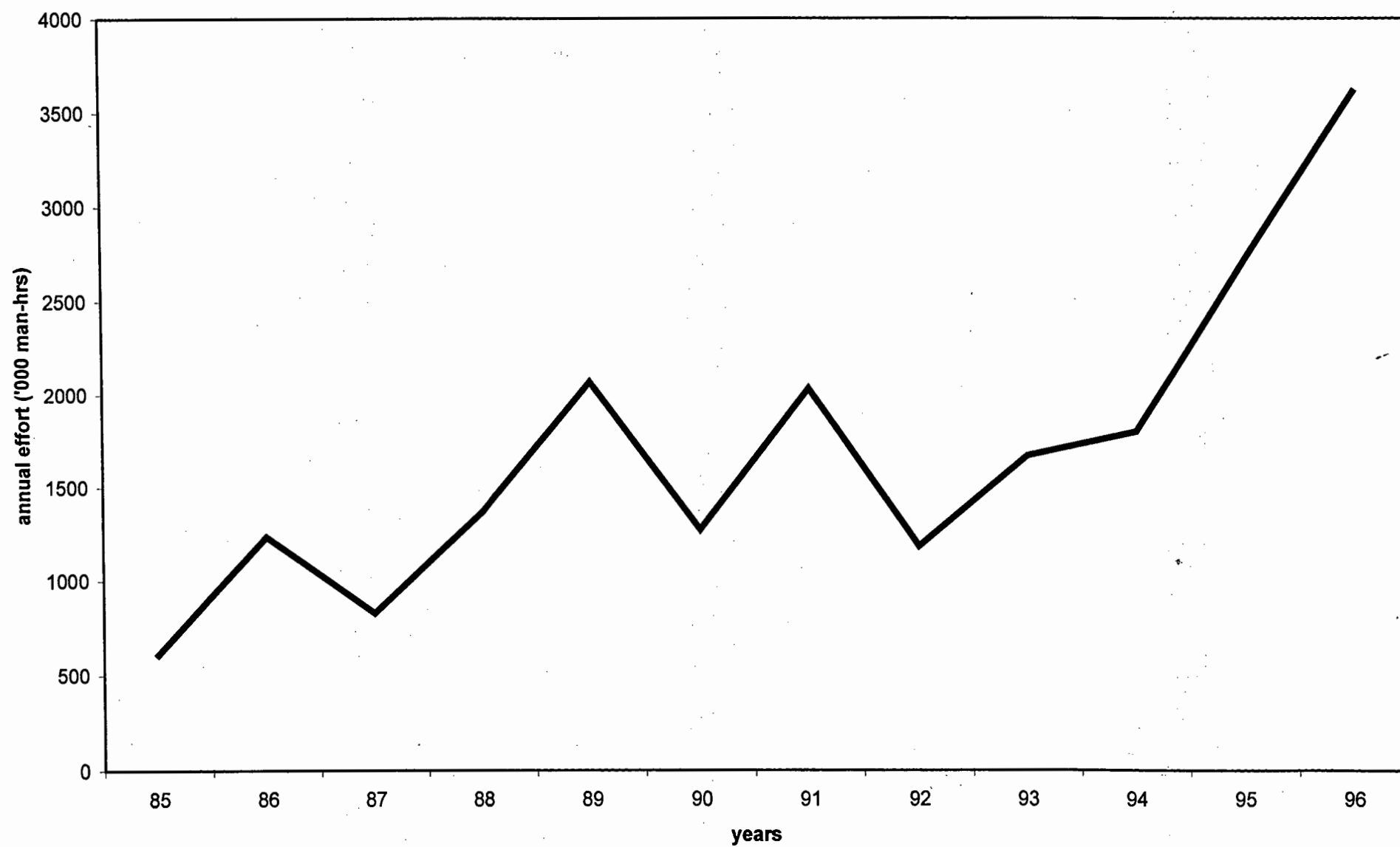


Fig. 3.3: Annual standardized effort in the jig fishery, from 1985 to 1996.

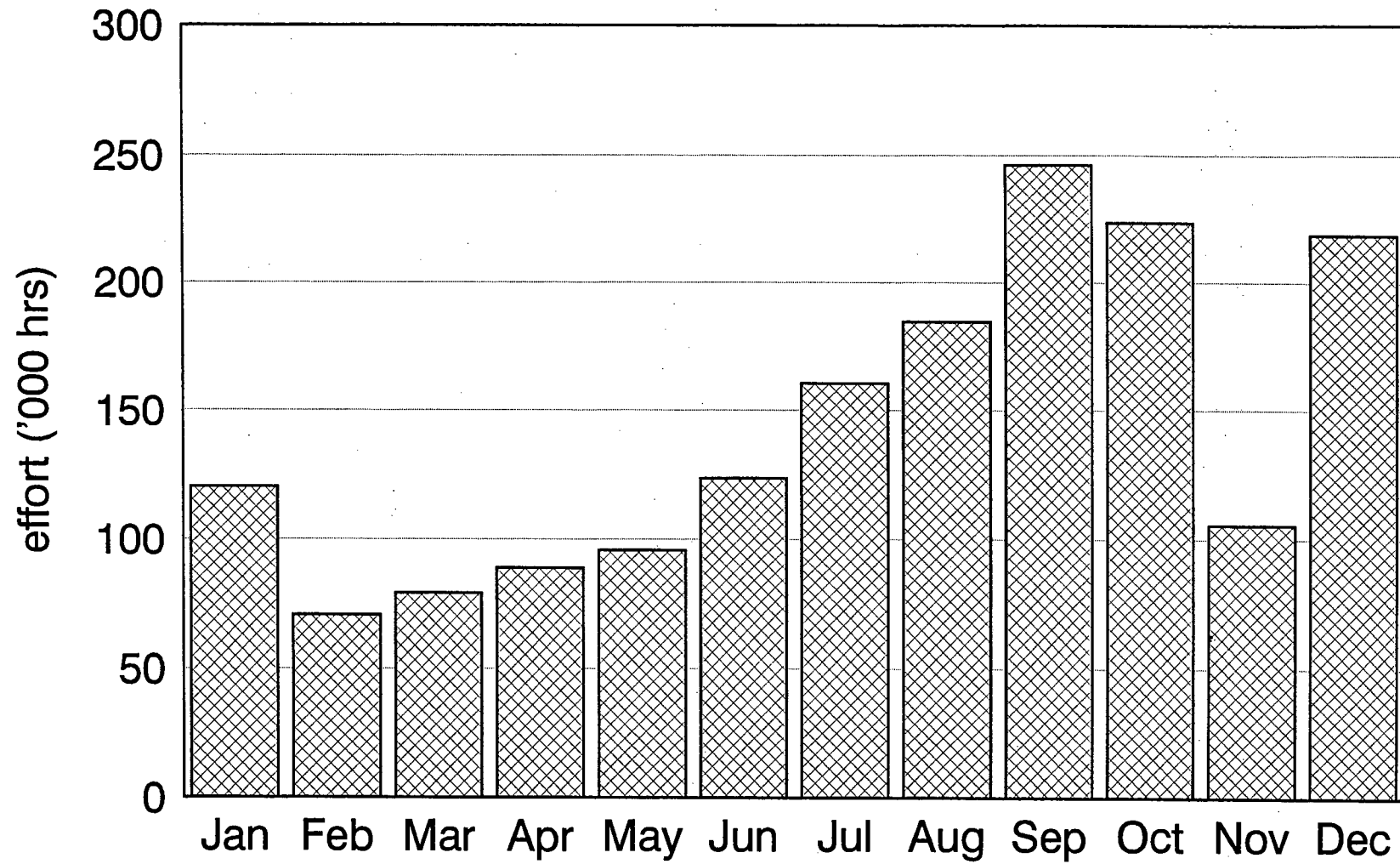


Fig. 3.4: Average monthly effort (in hours per man) in the chokka jig fishery, data from 1988 to 1995.

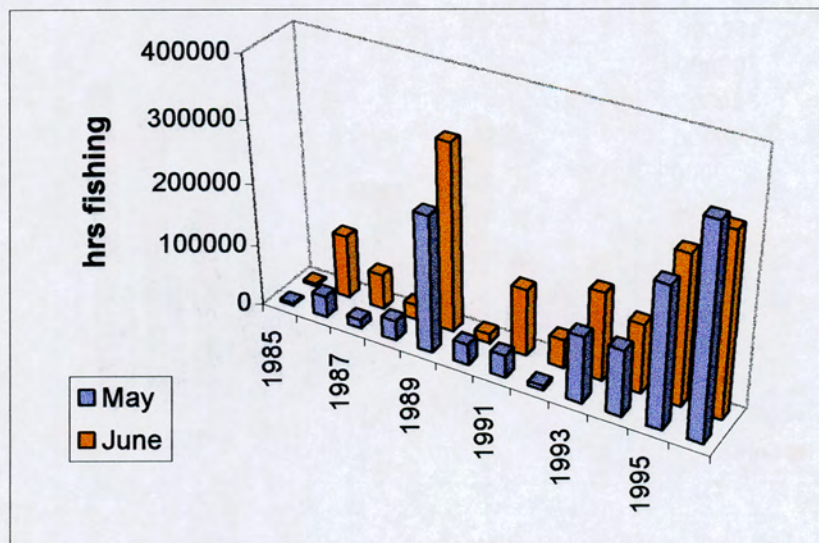
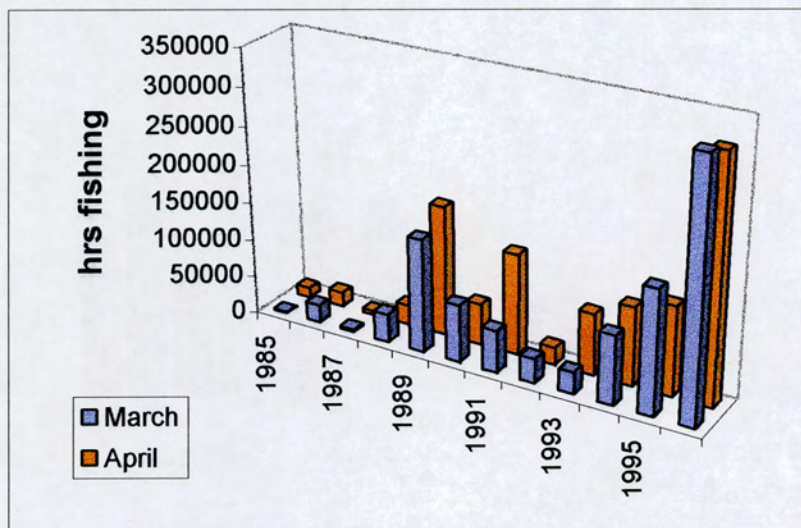
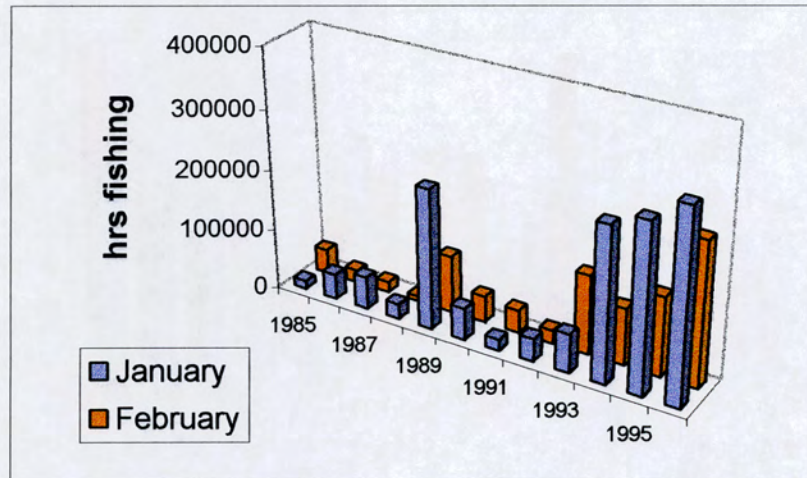


Fig. 3.5: Fishing effort (hours fishing) exerted in the jig fishery per month, from 1985 to 1996.

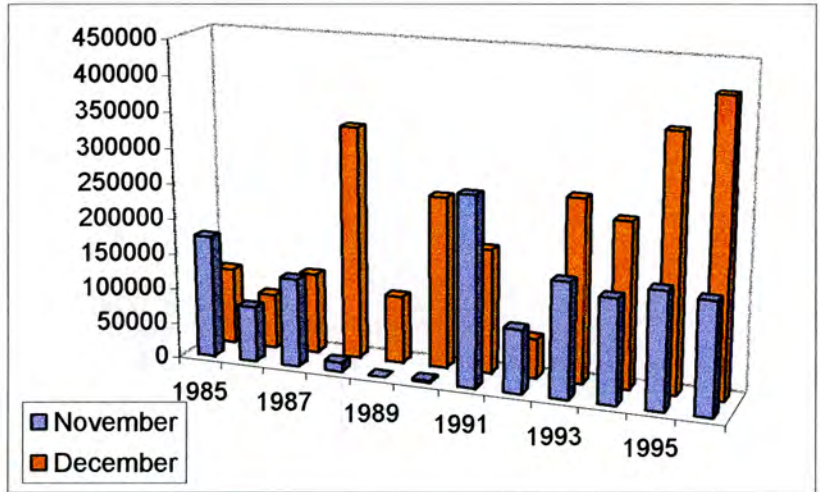
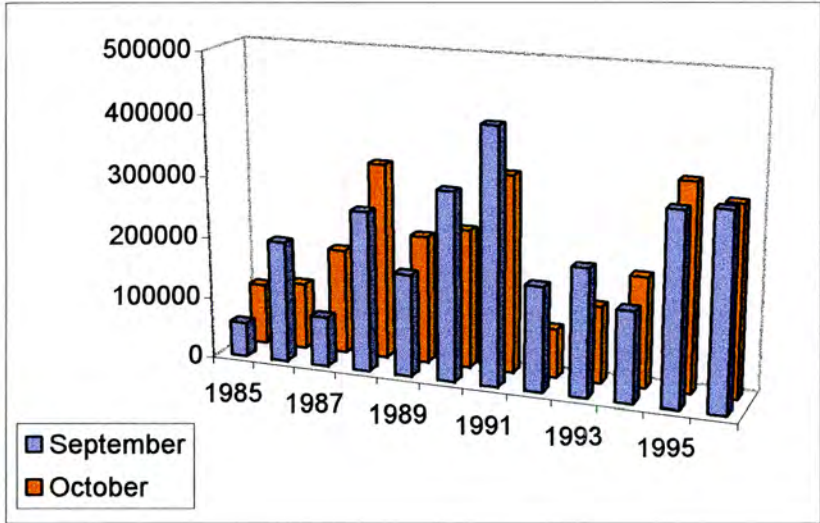
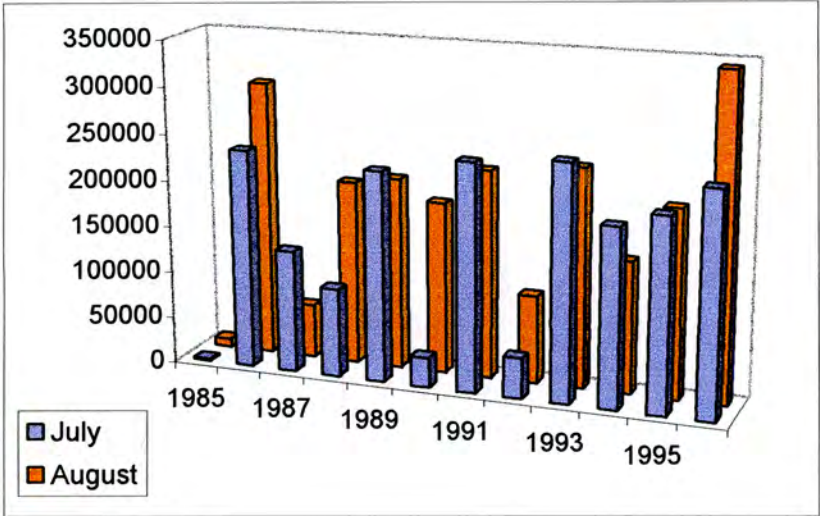


Fig. 3.5: Fishing effort (hours fishing) exerted in the jig fishery per month, from 1985 to 1996.

spawning grounds, and only those vessels with freezing facilities, powerful lights and suitable accommodation that allows them to spend several days at sea can continue fishing for the species in deeper water, farther offshore, where the squid are still available.

The monthly effort, expressed in total number of hours, is plotted in Figure 3.5 for the years 1985 - 1996. Particularly noticeable are the differences in the trends for the first and second halves of the year. While the effort was relatively low until 1992 or 1993 for the months January - June, with the exception of 1989 (a year of good chokka availability), it increased substantially in the first half of the year thereafter. This change in pattern is related to the increasing proportion of freezer boats in the fleet, which are able to catch chokka throughout the year. For the months July - December, effort was more evenly spread from year to year. The effort pattern observed in November is the result of a closed season of variable length first implemented in 1988.

3.1.4. *Spatial distribution of jig fishing effort*

Jig catch positions are reported only in relation to their position in respect to the coast. A lack of reference to distance from the coast, expressed either in terms of exact latitudinal and longitudinal position or water depth, did not seem to be a problem in the past because most of the jigging targeted the inshore spawning operations. However, at present, with the gradual move towards freezer boat operations and a resulting increase in fishing farther offshore, this lack of information creates difficulties in interpreting the CPUE data.

Patterns of distribution of fishing effort in relation to 12 main areas along the coast situated between East London and False Bay (see Fig. 1.1 for these locations), are shown in Figure 3.6 for the initial two years of the fishery and for two recent years:

1. 1985 and 1986, taken as representative of the developmental phase of the fishery;
2. 1995 and 1996, taken as representative of the current (mature) status of the fishery.

The comparison suggests an increase in effort over time in the areas between Port Alfred

and Plettenberg Bay, and a decrease off the False Bay grounds. While the increase is probably related to the general trend in fishing effort, the decrease could be linked either to changes in abundance or distribution of the stock over time, or to changes in fishing practices related either to the proximity to processing plants or other practical reasons.

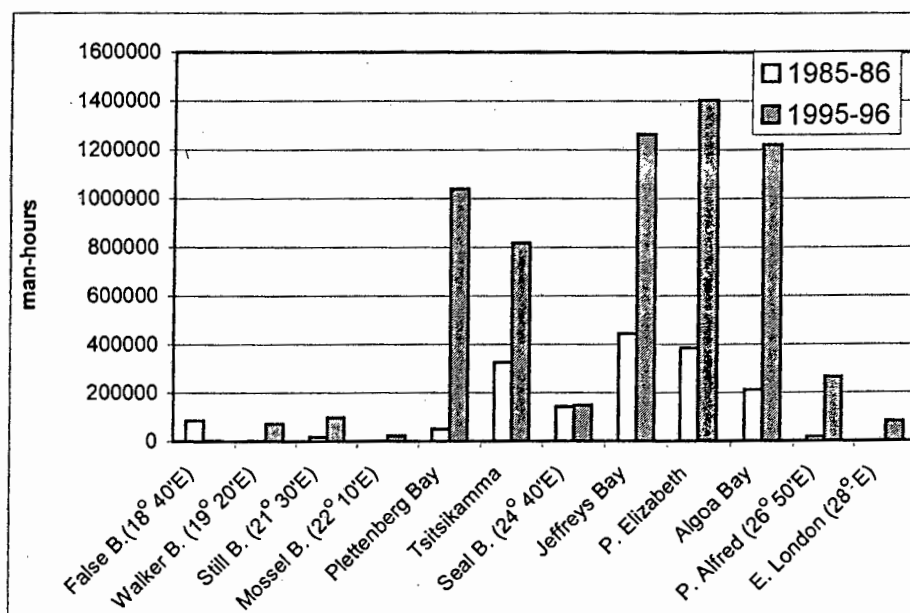


Fig. 3.6: Jig fishing effort per area for two early years (1985 and 1986) and two recent years (1995 and 1996) in this fishery. See Fig. 1.1 for geographic locations if longitude is not indicated in the labels.

3.2. CHOKKA TAKEN AS BY-CATCH IN THE DEMERSAL FINFISH FISHERY

The jig fishery is well described and has been relatively stationary in space over time. A second source of squid catches is the trawl fishery (table 1.I). This has shown a decline in CPUE over time. Changes in the distribution of this fishery, which could indicate whether the decline is a reflection of changing fishing patterns or a decline in abundance, are discussed in this section.

The bottom trawl fishery off South Africa started, around the turn of the century, for Agulhas sole, despite hake already being known as an abundant resource (Payne 1989). Presumably, some squid have always been caught by such trawling activities. However, during the 1970s and early 1980s, good catch statistics reveal that squid were landed by both local and foreign trawlers; until then, however, there was no jigging. While the local fleet targeted mainly on hake or, to a lesser extent, sole, and squid was only a by-catch, squid were eagerly exploited by Japan from around 1974 to meet an increasing demand in Japan for loliginid squid (Sato and Hatanaka 1983). The South Coast trawling industry can be divided into three sectors (Augustyn 1989):

- a) a South African offshore component fishing off both West and South coasts, in water deeper than 100 m and concentrating mainly on the two species of hake;
- b) a South African inshore component, fishing exclusively on the South Coast in water up to 110 m deep, although in recent years this has extended to 150 m (P. F. Sims, SFRI, pers. comm.), largely for sole and shallow-water hake;
- c) a foreign fleet consisting of a small number of Japanese and Taiwanese vessels, operating in waters deeper than 110 m off the South Coast, catching hake, horse mackerel and chokka.

At present, the first two sectors still operate under similar conditions, but foreign permits had been phased out by 1992.

The hake fishery expanded rapidly in the 1950s and, after a period of gradual increases in catches and a peak in 1972 (Payne 1989), the CPUE dropped to almost uneconomic levels by the mid 1970s. The first action to protect hake took place in 1975,

when a minimum stretched-mesh size for hake fishing of 110 mm was implemented. However, this regulation did not apply to the entire South African coast for, as off Namibia, a 75 mm mesh-size for mixed-species trawling was in place for bottom trawl fishing east of Cape Hangklip (i.e. the South Coast). The effect of mesh size on catches of *Loligo vulgaris reynaudii* was investigated by Hatanaka *et al.* (1983) and by Uozumi *et al.* (1984) during a selectivity experiment using 90, 105 and 120 mm mesh sizes. Augustyn *et al.* (1993) concluded that those experiments showed that escape from the net was poor, even in the case of small squid, despite the rather large mesh sizes. A second major advance to protect hake was made on 1 November 1977, when a 200-mile exclusive fishing zone off South Africa was implemented (Payne 1989). This probably had more of an impact on squid catches than did the mesh size regulations, as the 200-mile area closed to foreign activity would have eliminated such trawlers (except the gradually reducing number allowed in terms of bilateral agreements) from the areas where squid aggregates.

The closure of the inshore bays for trawling between 1985 and 1987, and the prohibition, built into the deep-sea trawling permit, on operating off the South Coast inshore of the 110 m contour since 1978 (i.e. (a) above), are both measures that excluded the trawlers from the inshore grounds where chokka aggregate to spawn and could, as a result, have caused a decrease in the chokka by-catch. The impact on chokka catches of net liners (although the extent of usage of such illegal nets can only be speculated upon) is probably minimal.

Catch statistics of chokka squid are available from trawlers since 1971. Annual chokka catches taken by foreign trawlers, South African trawlers and by jigging are shown in Figure 1.1 from 1971 to 1995. There is a clear gradual decrease in chokka catches made by foreign trawlers since their peak in 1974 and 1975. A difference in permit conditions between the South African deep-sea fleet and the foreign vessels, an irritant to local operators, resulted in the creation of a large area on the central Agulhas Bank where only foreign vessels could operate (the so-called "foreign triangle"). The foreign fleet in that area from 1973 to 1978 harvested substantial quantities of chokka (Japp *et al.* 1994). Foreign catches declined more rapidly after 1983, when increased restrictions were placed on the fleets of those countries that had retained a bilateral

fishing agreement with South Africa after 1977.

Catches by local trawlers also declined from 1974, and jigging catches increased rapidly after 1984. Although the declining trend in foreign trawler catches, especially those of Japan, which directly targeted chokka, can be explained by their gradual exclusion from South African waters, the reasons for the decline in local trawler catches are not obvious. Although some regulations (e.g. closure of bays) could have precluded trawlers from operating in areas of high density of chokka, other events, such as changes in fishing pattern or an overall decline in the resource, could well be manifest in the decline in the annual catch. An analysis has therefore been undertaken to detect possible changes over time in the distribution of fishing effort exerted by trawlers during this period in the history of chokka exploitation. Further, obvious changes in the depth ranges and seasonal changes in fishing operations could have had an impact on chokka catches, and they too are investigated. Finally, trends in catch per unit effort (trawl CPUE), as a possible indicator of resource abundance, are analysed.

3.2.1. Data

Detailed information from the trawl fishery on catch position, trawl duration and species composition of each trawl, as well as on vessel characteristics, is available only from 1978. Trawl data from 1978 to 1996 that coincide with the main area of chokka distribution were analysed to investigate possible changes in fishing patterns. Only hauls made south of Cape Columbine and shallower than 300 m were included in the analysis, to avoid including zero catches in areas where chokka occur only rarely. Normally, more than one trawl took place per day. In some cases, although the trawl details (including the trawl duration) were recorded, the catch per drag was not, and only the total catch for the day was reported. The proportion of catch-by-day returns, compared to returns by drag, varied over time. Whereas, only about 5% of the approximately 550 000 observations recorded between 1978 and 1994 correspond to returns reported on a daily basis, most of the catch data for 1995 and 1996 were reported by day only.

In order to extend the analysis to the most recent years, a selection of the data from 1978 to 1994 and all the data from 1995 and 1996 were combined. Data by

individual drag were used for the years 1978 – 1994 only, because relating catch per unit effort (trawl CPUE) to catch position and date is required for the analysis performed below; most of the catch returns were reported by drag for those years. However, as most data for 1995 and 1996 were reported by day, effort data had to be accumulated on a daily basis to compute trawl CPUE, which for the purpose of this analysis is expressed as kilogrammes caught per hour trawled. Assuming that a vessel would not have steamed very far between trawls in any given day, the catch position corresponding to the last drag was allocated to the catch and effort data of that day. As a result of the different formats in which the catch and effort data have been reported, the absolute numbers of observations are not directly comparable between the 1978 – 1994 data and the data for 1995 and 1996. Therefore, relative proportions are used in the analysis to circumvent this problem when the two sets of data are combined.

When the total catch in a day was apparently more than 80 tons, an error was assumed and the observation was omitted, because a single trawl cannot realistically contain more than 25 tons, and a maximum of three trawls could be expected in a day when catch rates are so high (R. Leslie, SFRI, pers. comm.). Finally, three observations in September 1989 corresponding to Boat Number 248 recorded unusually large catches of chokka. As an error in the data was suspected, that entry was eliminated. The combined data set contains 533 502 records between 1978 and 1994 (before accumulation per day) and close to 20 000 observations in total for 1995 and 1996.

3.2.2. *Distribution of trawl fishing effort. Spatial and temporal patterns*

In order to study the spatial distribution of trawling effort in the area of study, the number of drags per interval of 10 minutes of latitude and 10 minutes of longitude was computed for two periods: 1978 – 1984 and 1985 – 1994. Data for 1995 and 1996 were not included because catch information by drag is not available for those years and because the data until 1994 were considered likely to be representative of the general fishing patterns which characterise the most recent period. The results are plotted in the form of contours in Figures 3.7a and 3.7b. Comparison between the two charts reveals similar patterns in the distribution of fishing effort, with maxima inshore off both

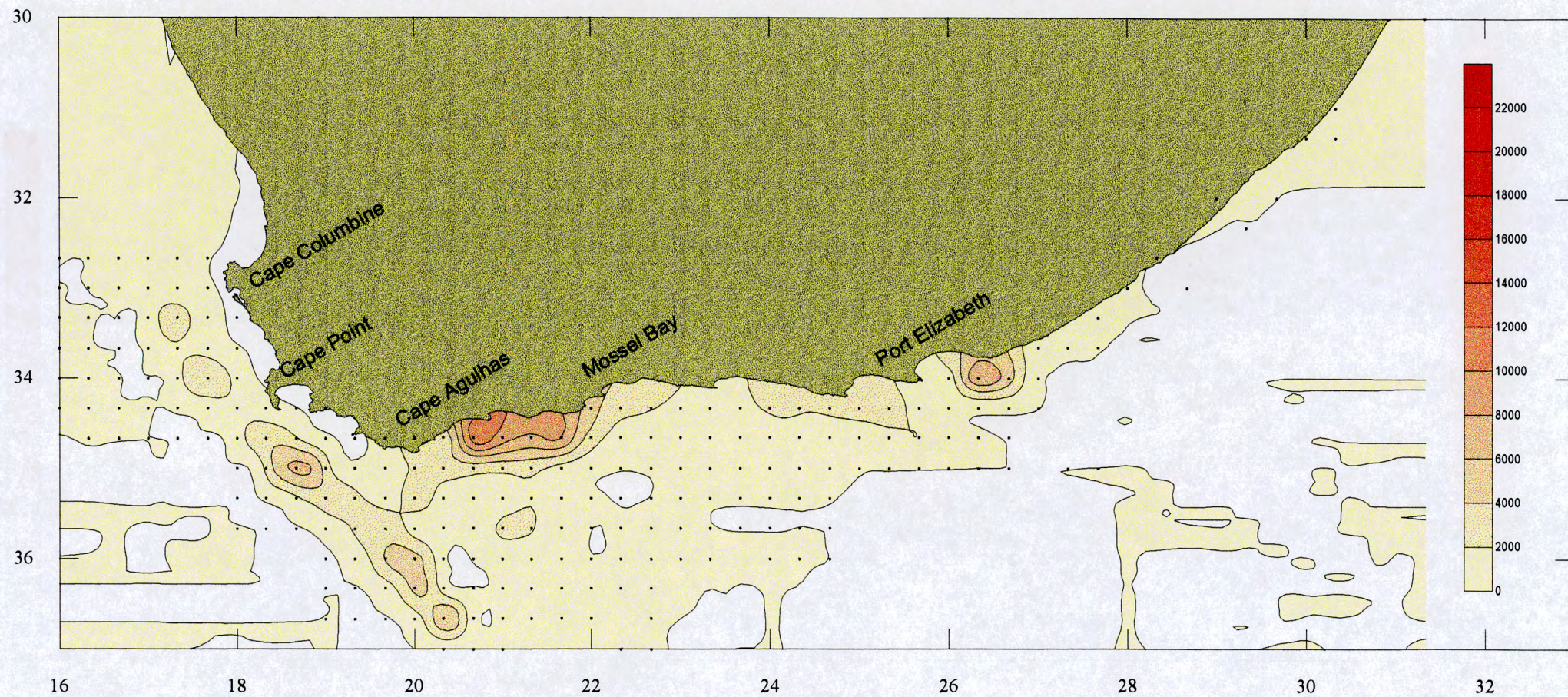


Fig 3.7a: Number of hauls per 10' x 10' block 1978 - 1984

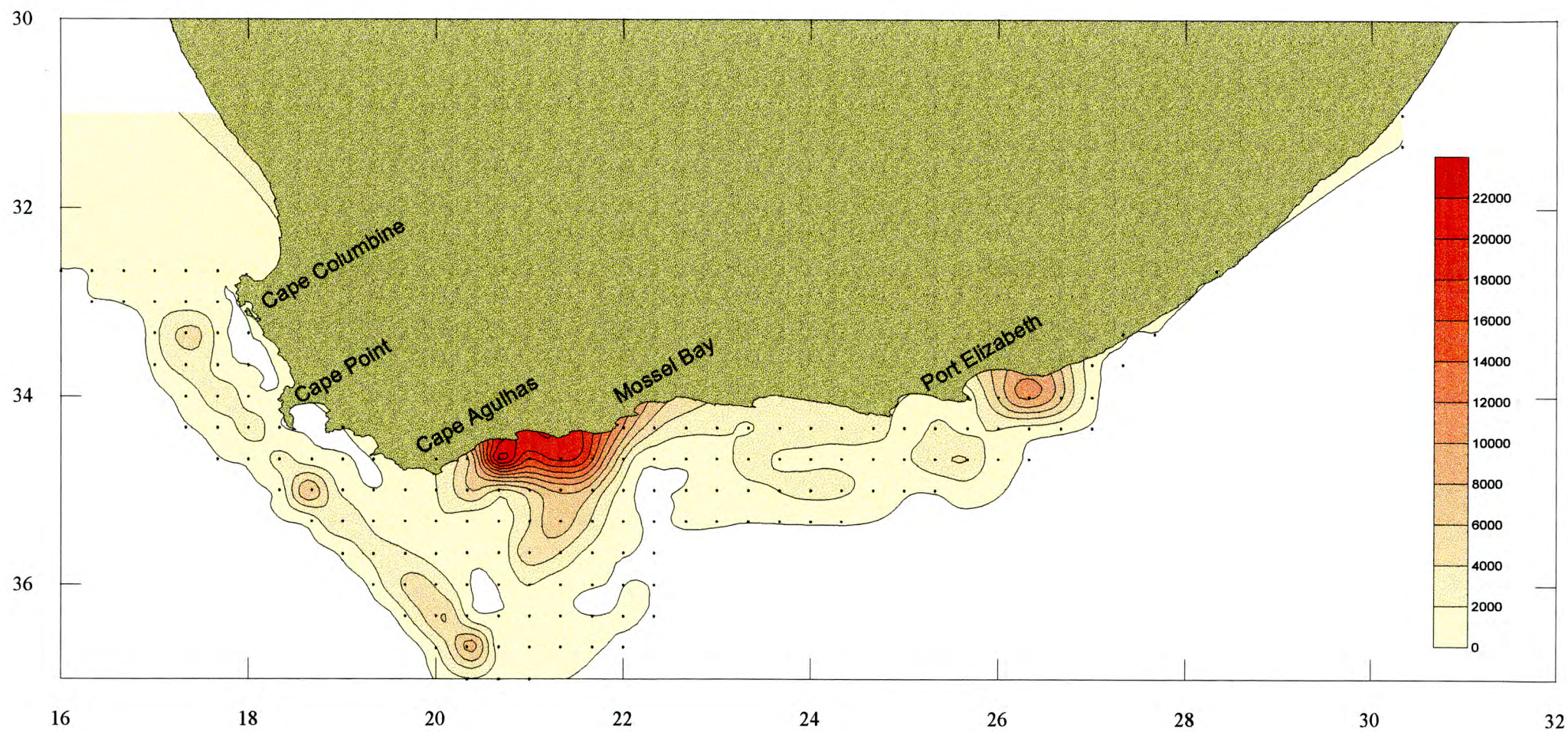


Fig 3.7b: Number of hauls per 10' x 10' block 1985 - 1994

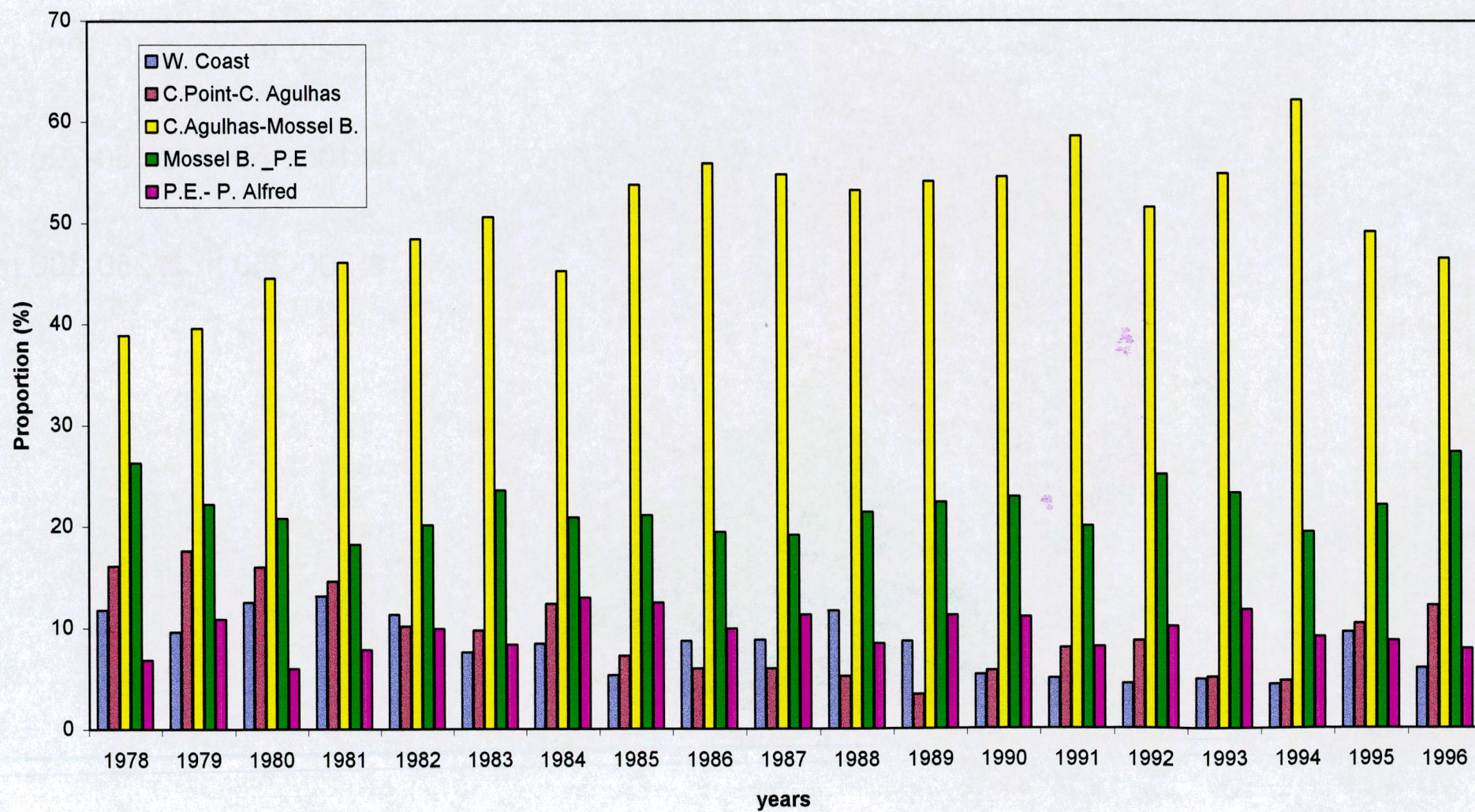


Fig. 3.8: Distribution of the trawls in the trawl fishery. Number of trawls that took place in each area over total number of trawls in that year (as %) from 1978 to 1996.

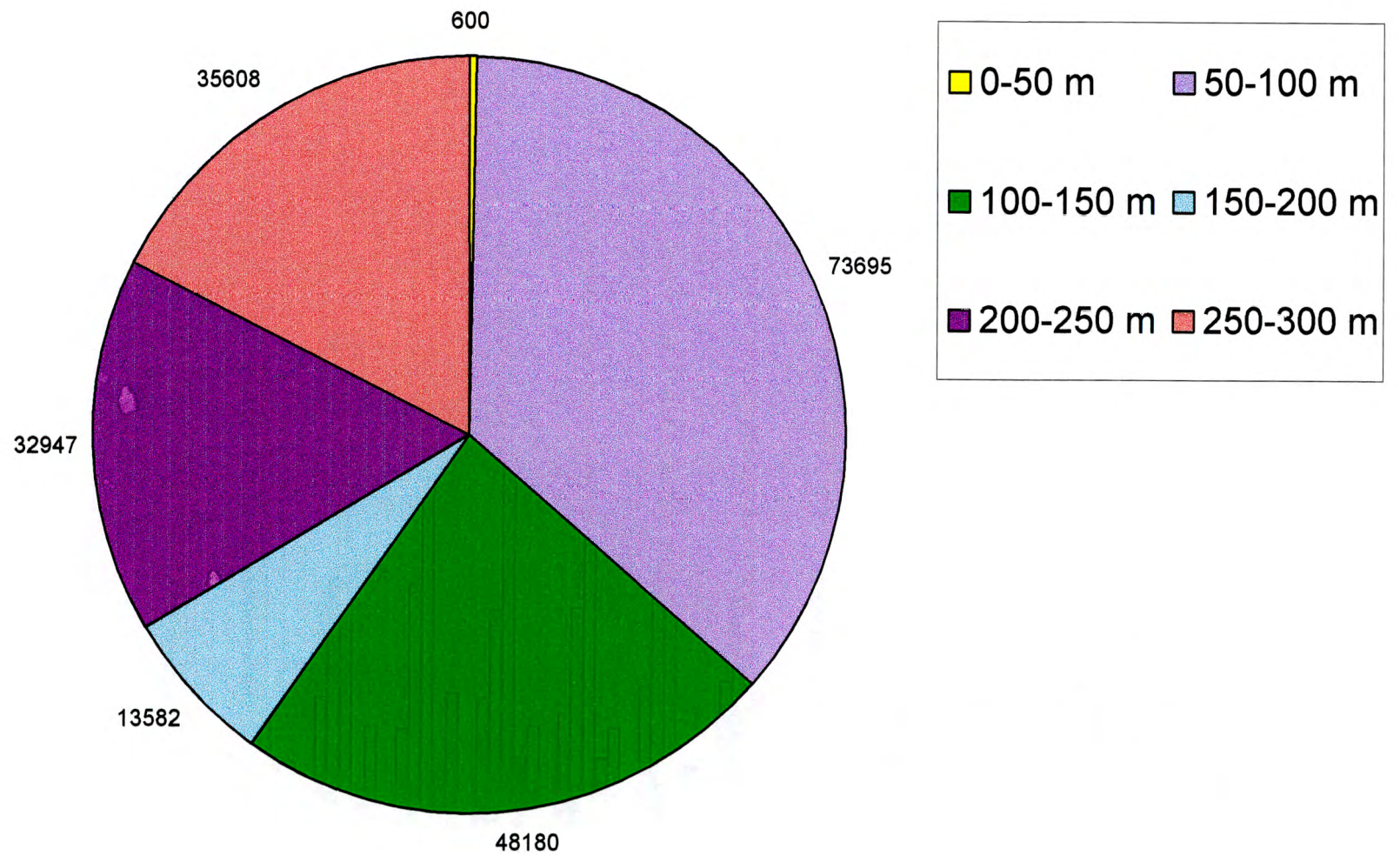


Fig. 3.9: Number of daily records per depth interval for the period 1978-1996.

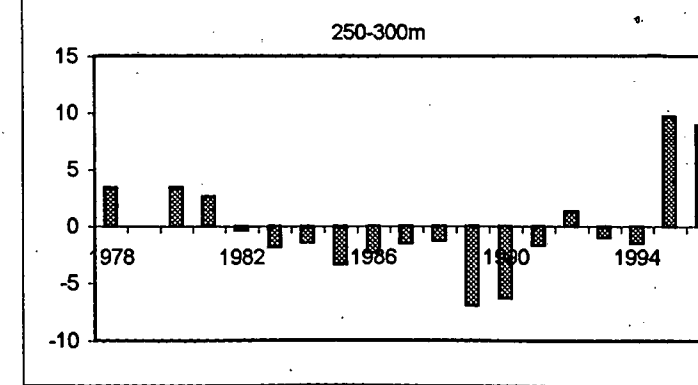
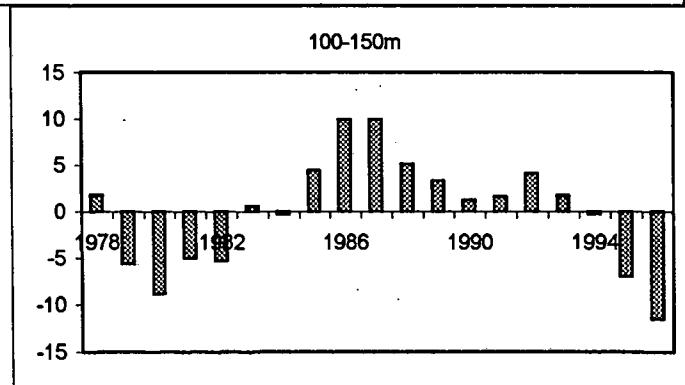
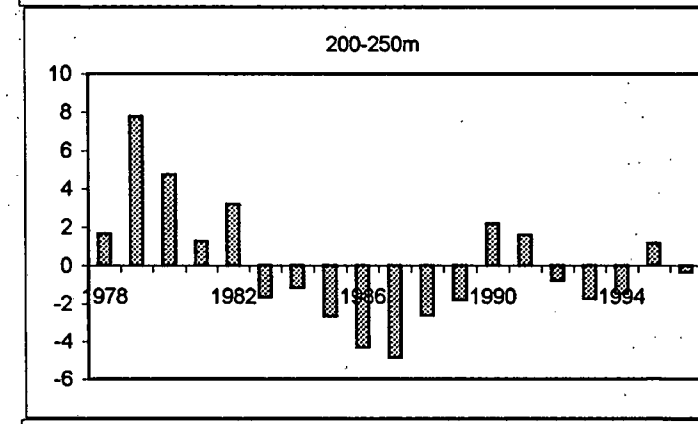
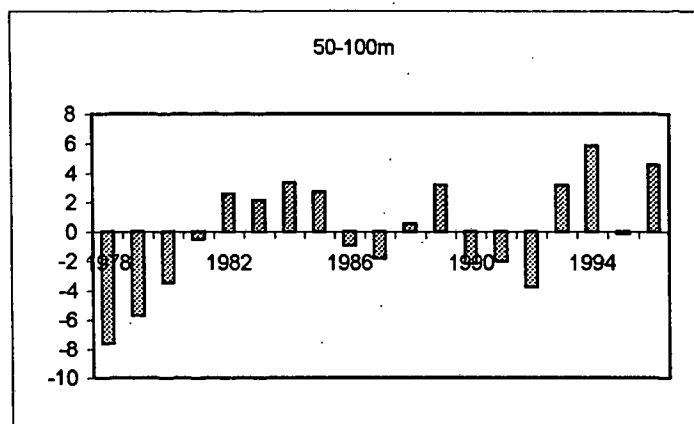
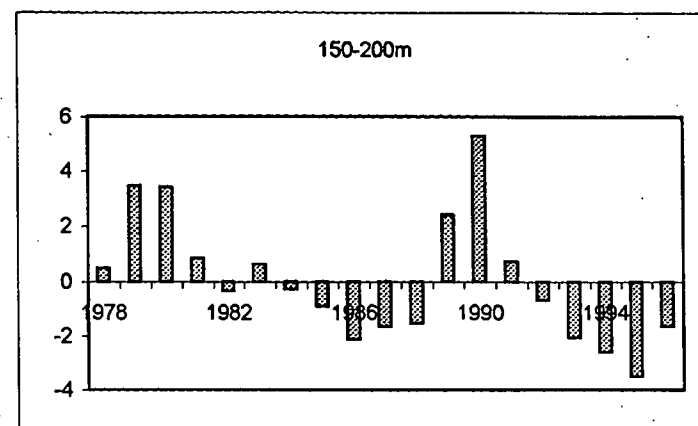
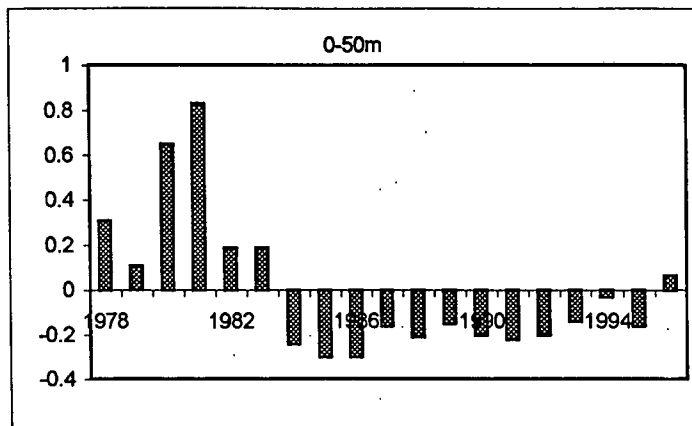


Fig. 3.10: Frequency distribution of trawls per depth range over time, the Y-axis shows the observed percentage less the average (the average percentages corresponding to each depth interval are: 0.3, 39.6, 25, 6.5, 15.4 and 13.3 respectively).

Mossel Bay and east of Port Elizabeth. Examination of the charts indicates that another important area for trawling during the whole period considered was offshore between Cape Point and Cape Agulhas. However, a reduction over time in the overall area covered by trawling operations is evident, as the trawlers seem to have tended to withdraw from the offshore fishing grounds in the more recent period.

The percentage distribution of drags between 1978 and 1996 by area and year was computed to investigate changes in the spatial distribution of trawling operations in the area of study. The study area was divided into five regions along the coast, taking into account the distribution of chokka and the main geographical reference points. These areas are:

1. West Coast: between Cape Columbine and Cape Point;
2. Western Agulhas Bank: between Cape Point and Cape Agulhas;
3. Central Agulhas Bank, between Cape Agulhas and Mossel Bay;
4. Eastern Agulhas Bank, between Mossel Bay and Port Elizabeth and
5. East Coast: east of Port Elizabeth.

The bar diagram in Figure 3.8 represents the proportion of trawls that took place in each area between 1978 and 1996. Most of the drags, between 70 and 80%, took place east of Cape Agulhas, area which includes the one where the main chokka spawning aggregations occur. While some decline in the proportion of trawls over time is shown for the West Coast and the Western Agulhas Bank, no clear trends appear in the other areas. The proportion of drags on the Western Bank was relatively high between 1978 and 1981, and then it started to decline gradually before increasing slightly in the last few years. The Central Agulhas Bank between Cape Agulhas and Mossel Bay is the area where most trawling traditionally takes place (Japp *et al.* 1994).

The distribution of trawling operations in relation to water depth over the period between 1978 and 1996 was also investigated. The results are plotted as a pie diagram in Figure 3.9, each segment representing the number of drags that took place in a particular depth range during the whole period analysed. Most of the trawling was between 50 and 50 m deep, and to a lesser extent between 200 and 300 m. There was little trawling

activity close to the coast, where good catches of adult chokka would have been expected, partly because of the rocky nature of most of the sea bed there precludes safe trawling.

Possible changes over time in catch position in relation to depth were investigated by computing the frequency of occurrence of drags per 50-m depth interval over the entire area of distribution of chokka. The percentage of drags that took place in a given year, less the average occurrence between 1978 and 1996, is plotted by depth interval in Figure 3.10. There is a clear decline in the proportion of drags after 1983 in the 0 – 50 m interval, coinciding with the closure of many of the bays to trawling. However, given the small percentage represented by these drags, the impact of this decline on the total chokka CPUE would be expected to be negligible, unless inshore catches were extremely large compared to those made in deeper water. There also seems to have been a larger proportion of drags deeper than 150 m prior to 1982.

The percentage distribution of drags performed per three-month period is plotted against year on Figure 3.11. Fishing effort appears to have been spread evenly through the year since 1978, except perhaps for the months April - June and to a lesser extent October – December, when the proportion of drags is smaller than in the rest of the year. This is probably the result of unfavourable winter weather conditions and summer seasonal lay-ups over the holiday season respectively. However, these seasonal trends have remained similar throughout the period considered and no temporal trends become apparent as a result of this analysis.

3.2.3. Annual trawl CPUE trend

The mean trawl CPUE was calculated for the years 1978 – 1996 and is plotted in Figure 3.12. The overall trend is downwards, and included a particularly sharp decline in CPUE after 1983, followed by a modest recovery in 1988 and 1989. Thereafter, the CPUE dropped again and remained low but relatively stable. It could be argued that a higher incidence of chokka-directed operations occurred in the early years and could thus have resulted in higher CPUE values then. Therefore, the incidence and general features of chokka-directed fishing operations are investigated to establish whether changes in the proportion of these operations over time could explain such a decline.

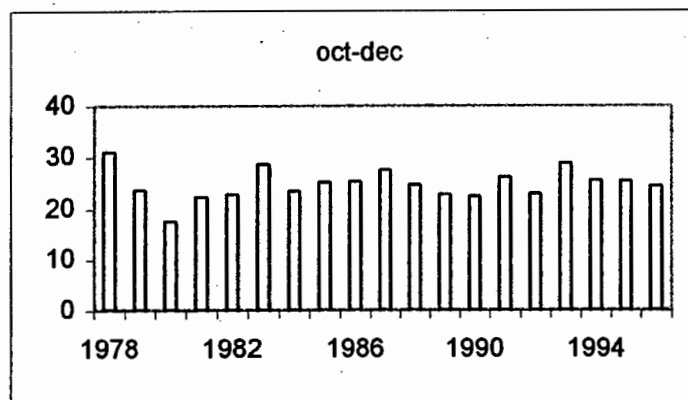
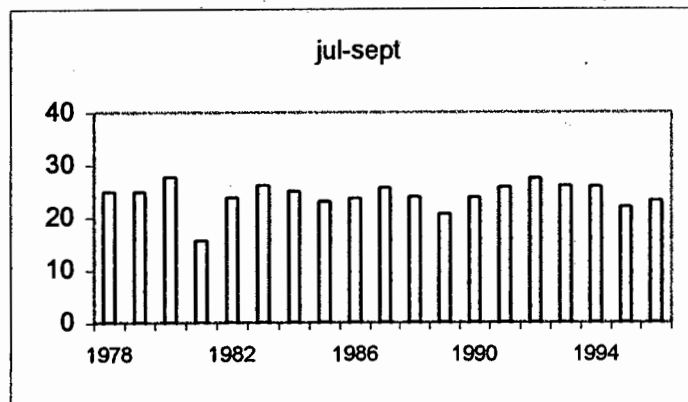
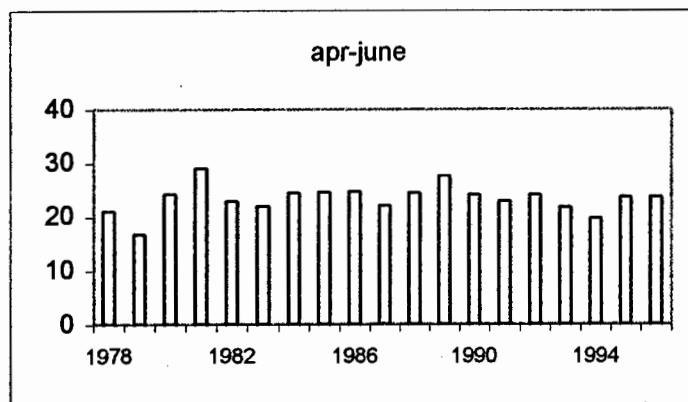
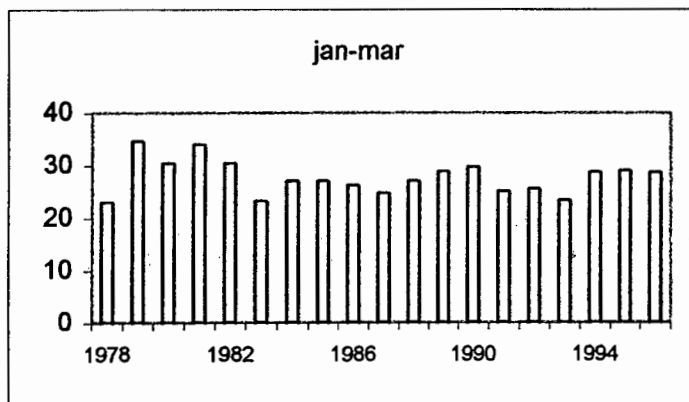


Fig. 3.11: Percentage distribution of trawls per season.

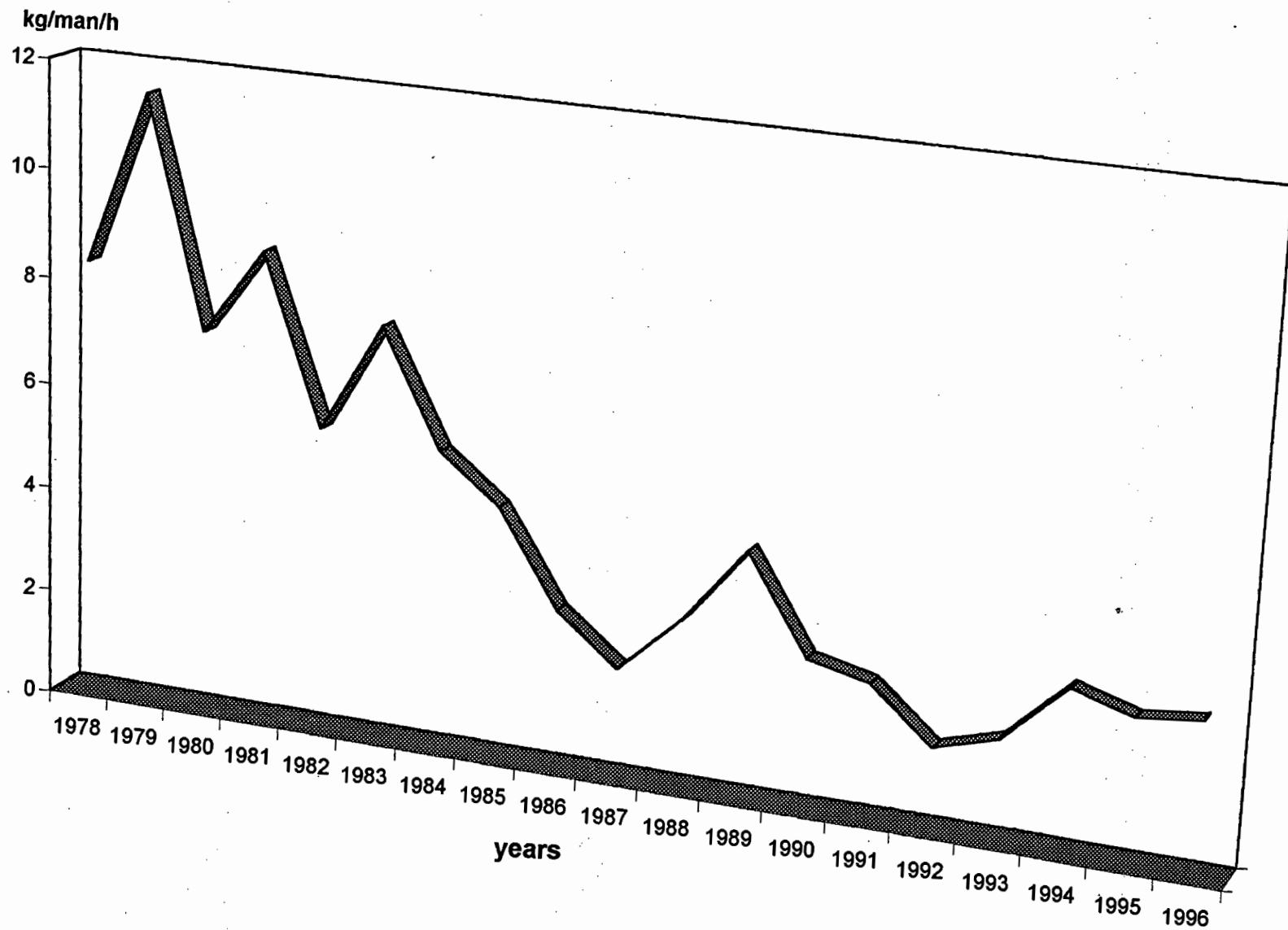


Fig 3.12: Nominal CPUE. Computations based on catch and effort data by boat and accumulated per day. Drags for which errors were suspected were not included in the calculations.

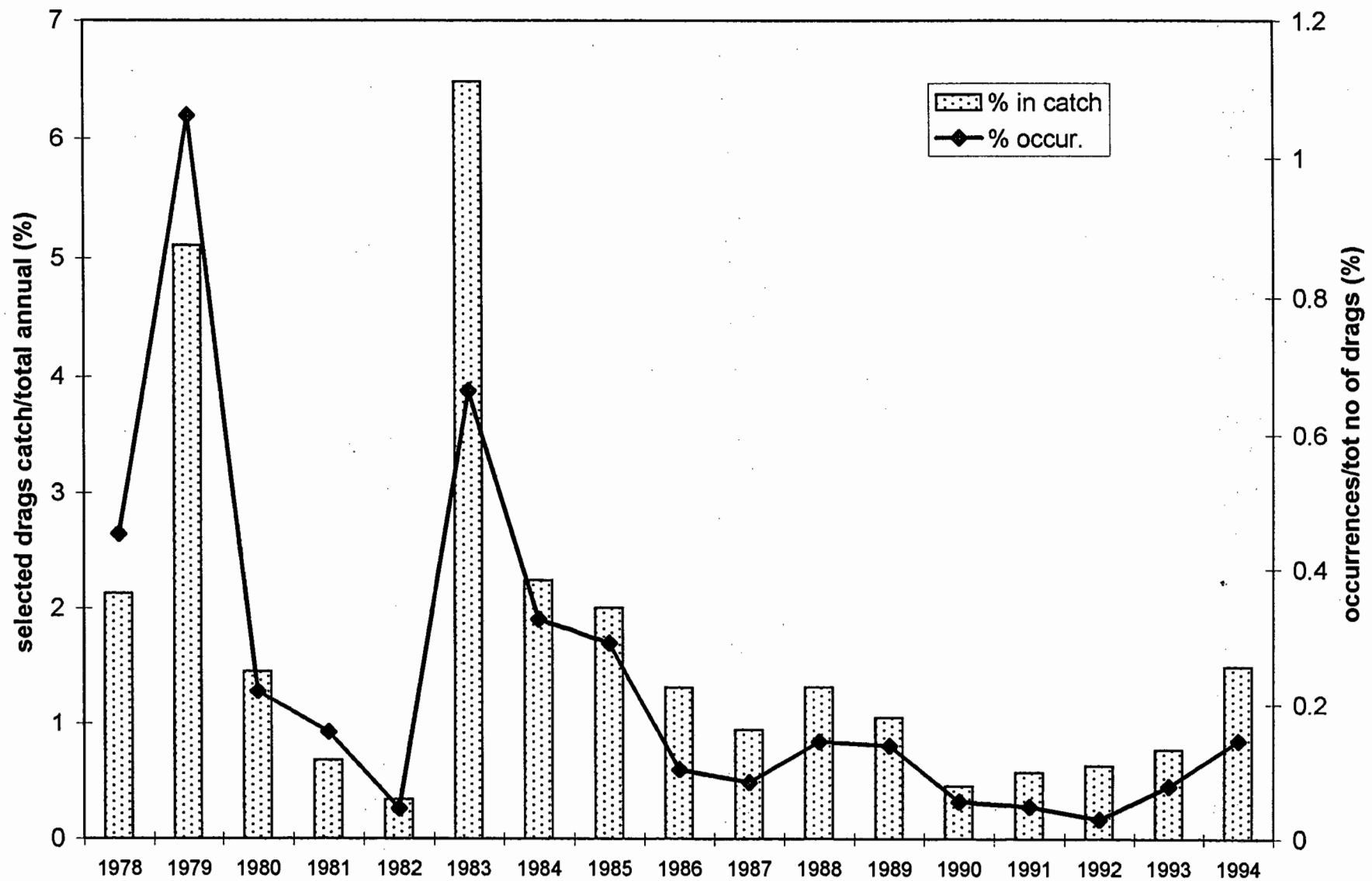


Fig. 3.13: Incidence of catches consisting of more than 50% chokka, 1978 - 1994. Left v. axis: percentage (in mass) of the total annual catch represented by those catches; right v. axis: number of occurrences divided by total no of drags in the year.

3.2.4. Influence of possible directed trawl catches

The file that contains information by drag between 1978 and 1994 was used to evaluate the impact of trawling operations targeting chokka squid directly on the annual estimate of CPUE. Drags where the percentage of chokka in the total catch was more than 50% could be suspected of being chokka-directed. The percentage occurrence and the percentage by mass related to the total annual catch are plotted on Figure 3.13. Although both percentages vary substantially between years, with maxima in 1979 and 1983, they are relatively small and cannot be expected to have made a major impact on the overall annual CPUE.

The average depth where the chokka-directed drags took place is plotted on Figure 3.14. The average lies between 100 and 150 m deep, with the exception of 1982, when chokka-directed trawling took place farther offshore. This indicates that, if South African trawlers target on chokka, they would not necessarily do so at inshore spawning aggregations, but may well catch them in deeper waters either before they spawn or when they are dispersing after spawning.

3.2.5. Trawl CPUE by area and by depth range

Further analysis of the distribution of CPUE for two main periods was undertaken to provide a more detailed description of the data used. The period 1978 – 1996 was divided into two periods: a period of high CPUE and a period of low CPUE, with the end of 1984 being taken as the cut-off point. Basic descriptive statistics for the trawl CPUE are:

- Number of records: 205 145;
- Mean: 5.04;
- Mode: 0

Table 3.II: Quantiles for CPUE (kg per hour trawled) from 1978 to 1996.

Quantiles							
100%	75%	50%	25%	0%	99%	95%	90%
177.1	4.33	0	0	0	58.5	27.2	15.97

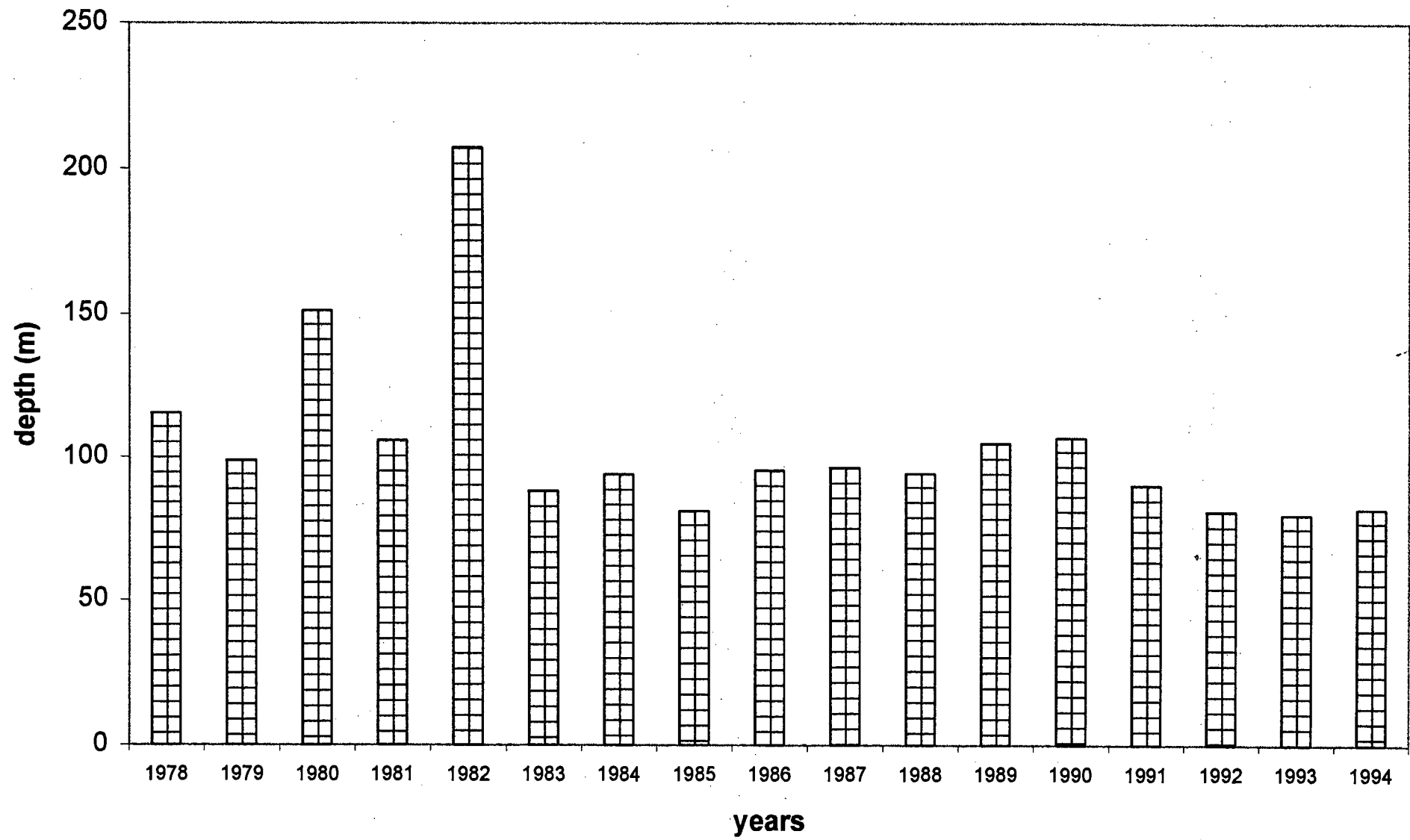


Fig. 3.14: Average water depth of drags with >50% chokka in the catch, per year.

The CPUE values, calculated on a daily basis, were grouped into six intervals for descriptive purposes: zero, $>0 - 3$, $3 - 10$, $10 - 25$, $25 - 80$ and >80 kg per hour of trawling. The cut-off points used to group the CPUE values were chosen taking into consideration the very skewed nature of the distribution and aiming to take a more detailed look at the differences in the distribution at low values of CPUE, where most of the observations lie. The numbers of occurrences recorded, expressed as percentages, are plotted on Figure 3.15. The plot shows clear differences between the percentages corresponding to the zero CPUE interval, and to the intervals corresponding to CPUE values >3 kg/h. However, it is probably the difference in number of zero CPUE observations between the two periods, close to 20%, which would have a larger impact on the annual estimate of CPUE.

The distribution of CPUE values, grouped in six intervals, was computed by area, the areas chosen being the same as described previously. The West Coast is the area with the highest percentage of zero occurrences and the area between Cape Point and Cape Agulhas has the greater incidence of high CPUE values (Fig. 3.16). The differences become even larger if the data are disaggregated into two periods (Fig. 3.17). In that manner, the percentage occurrence of zero CPUE values rises to more than 80% for the West Coast for the most recent period. The percentage of high CPUE catches in the area Cape Point – Cape Agulhas can be related largely to high values in the early years of the series considered.

The percentage distribution of the six CPUE categories is plotted on Figure 3.18 per 50-m depth range. The incidence of zeros is highest in the 250 – 300 m depth interval, suggesting that the offshore boundary of chokka distribution lies within that depth range. The incidence of high CPUE values appears to be low in the inshore interval (0 – 50 m), which is counter-intuitive given the fact that it is in this depth range that the large spawning aggregations occur. However, the aggregations have a patchy distribution and are found mainly in spring and early summer, and also mainly in the bays closed to trawling since 1985, so influencing the observed high frequency of zero catches as well as the low CPUE estimate, particularly when computed as a daily average. A major incidence of high CPUE values and a low proportion of zeros is observed in the depth intervals that lie between 100 and 200 m.

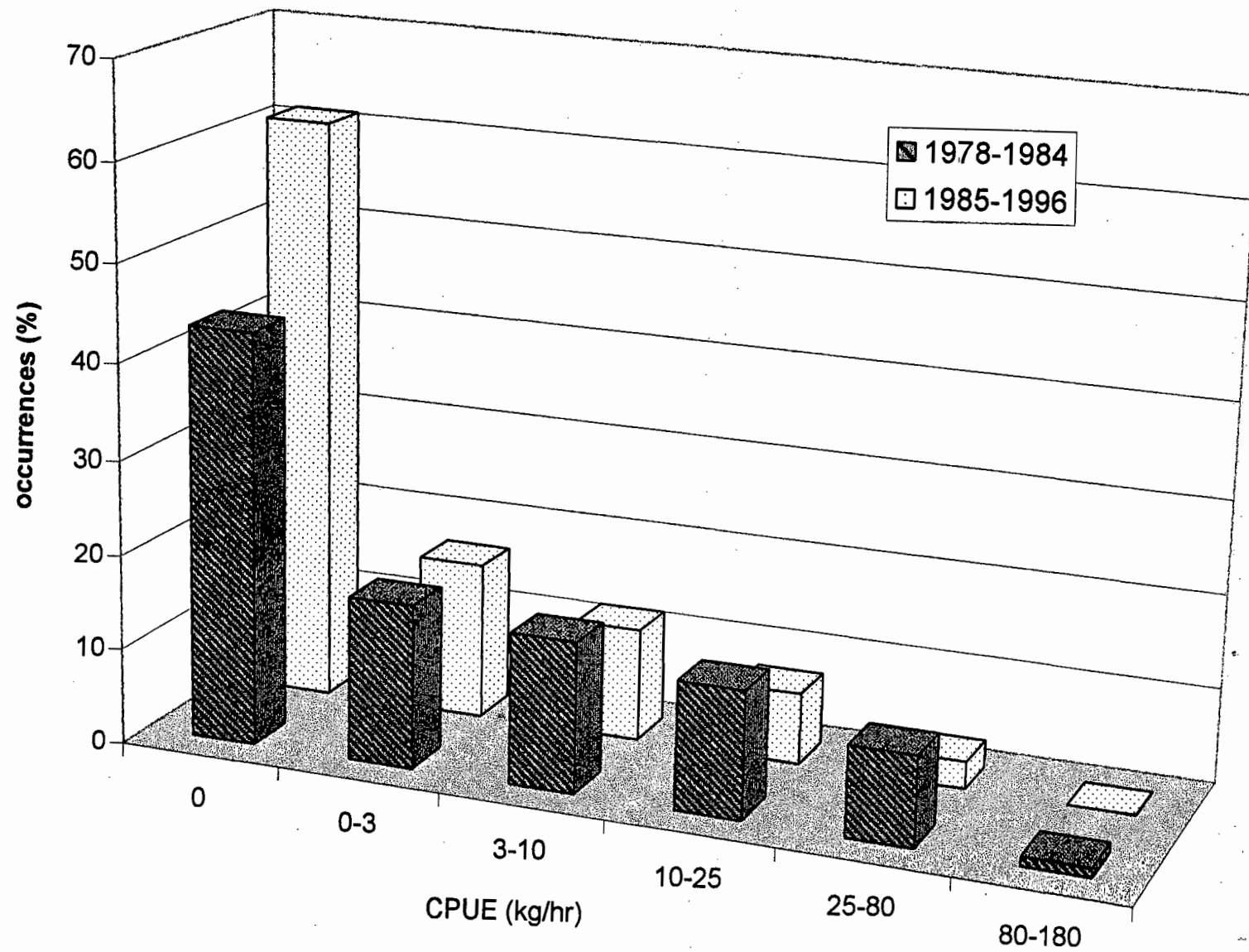


Fig. 3.15: Percentage distribution of trawl CPUE categories for two periods.

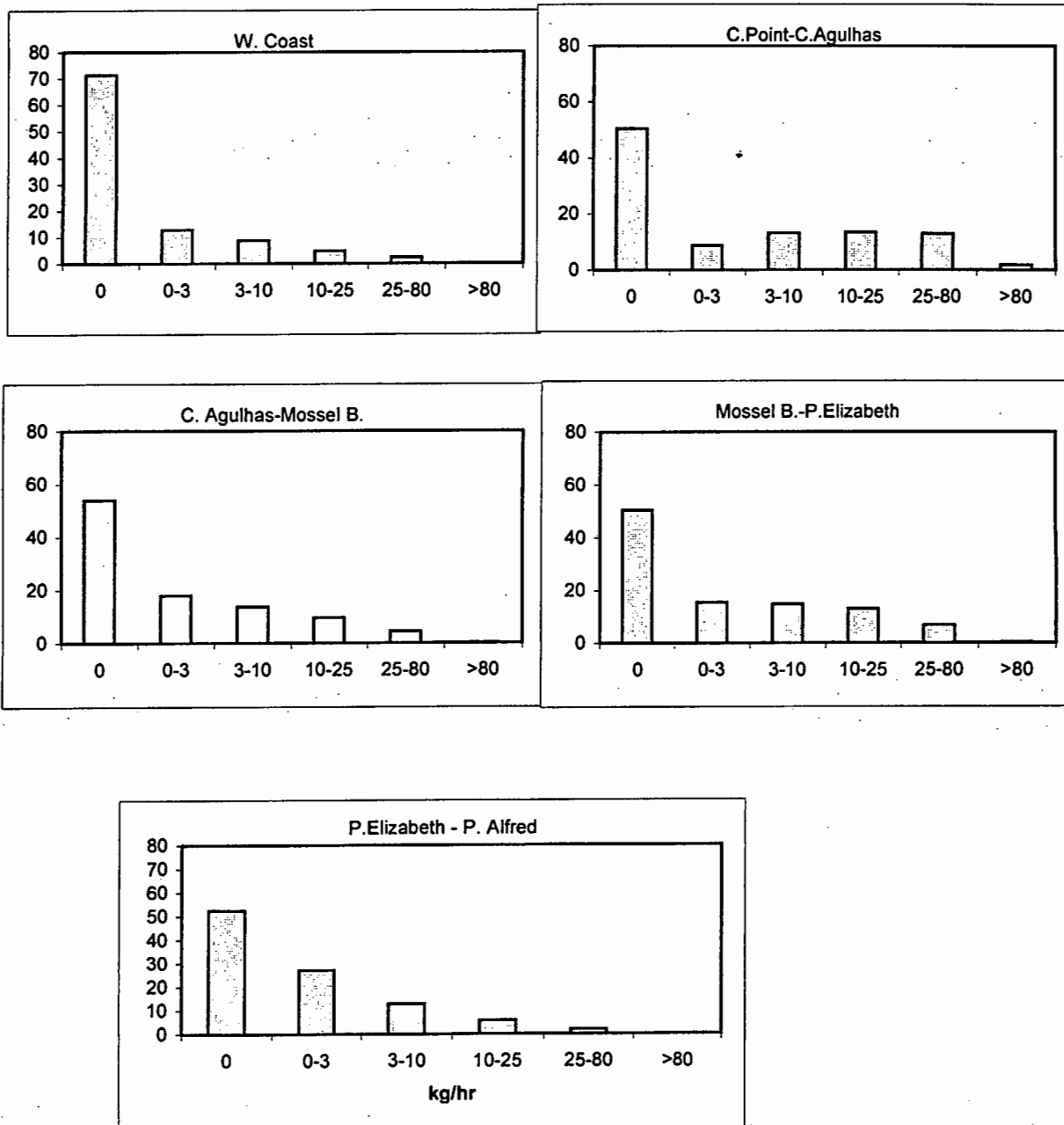


Fig. 3.16: Trawl fishery. Percentage distribution of six CPUE categories per area.

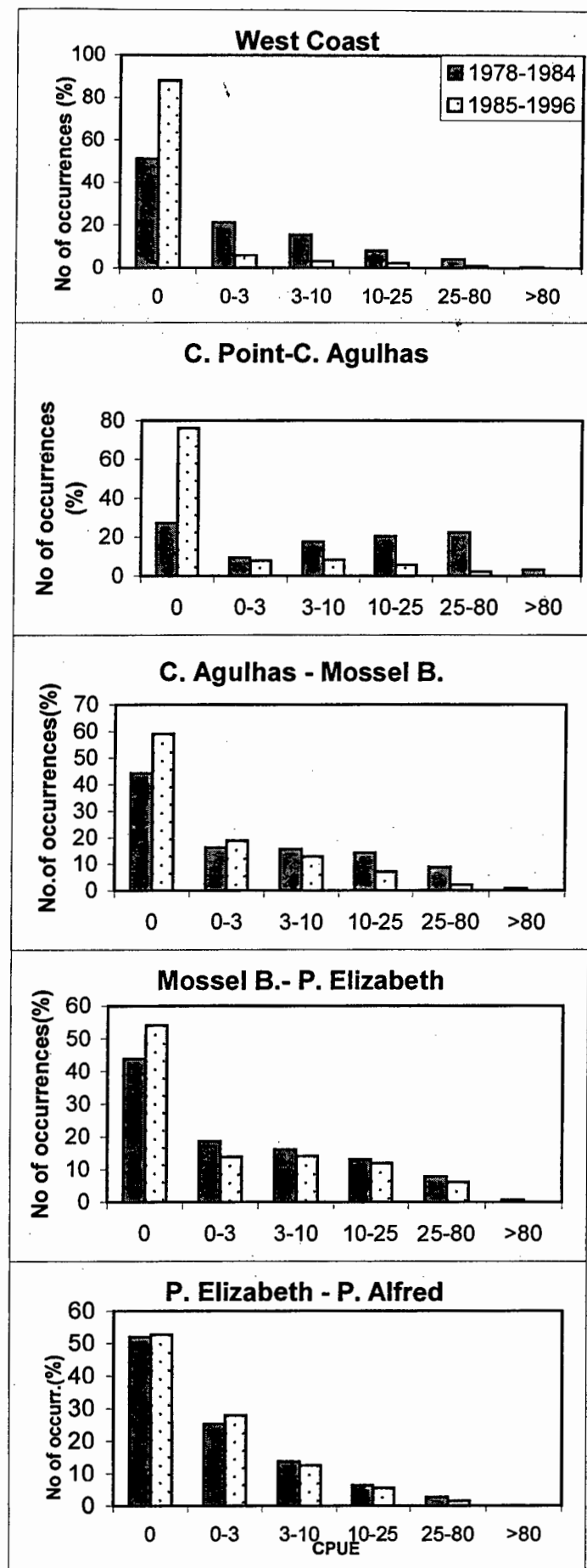


Fig. 3.17: Distribution of trawl CPUE categories per area for two periods: 1978-1984 and 1985-1996.

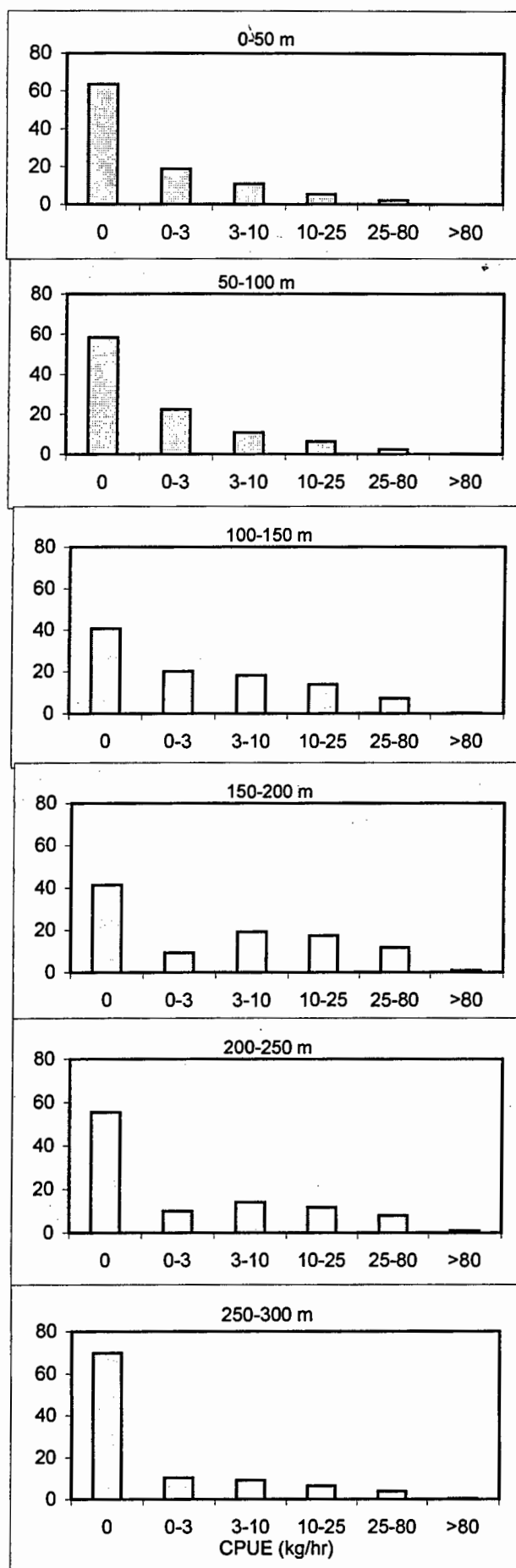


Fig. 3.18: Distribution of the trawl CPUE for 6 depth ranges (data from 1978 to 1994).

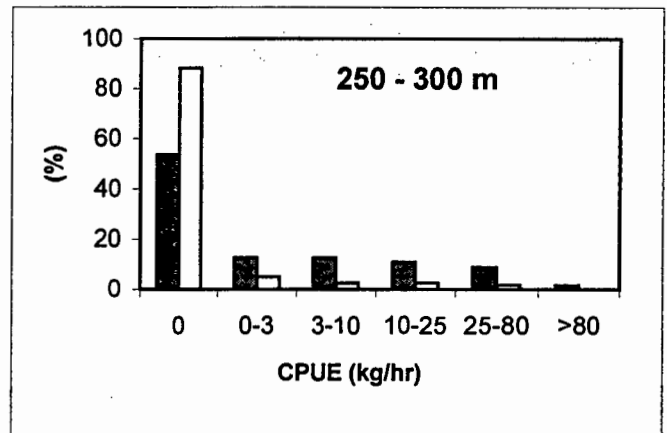
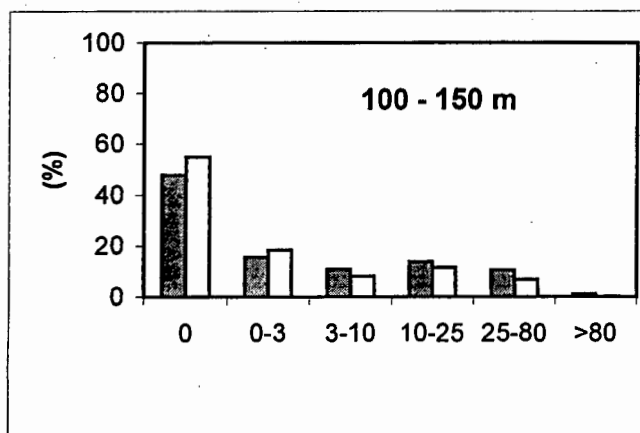
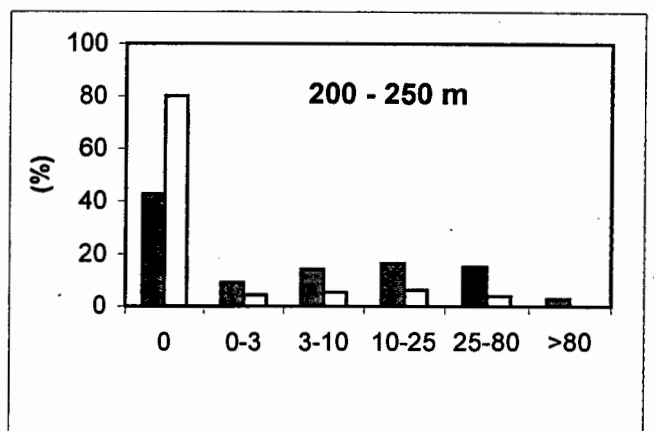
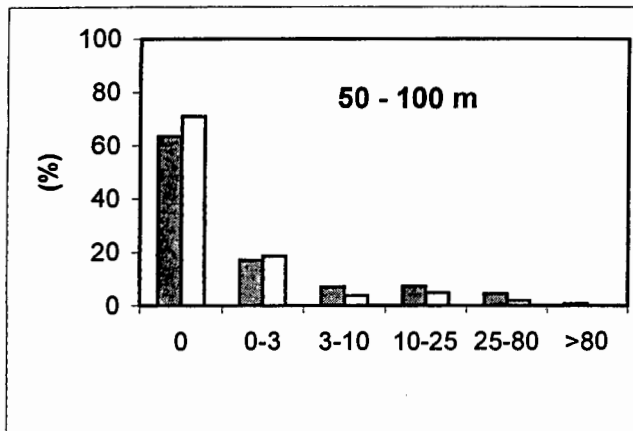
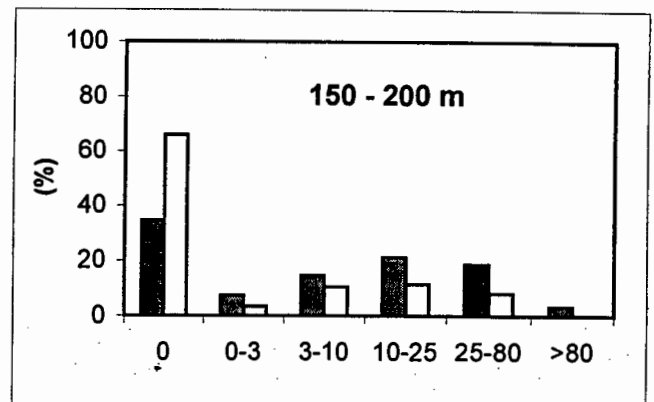
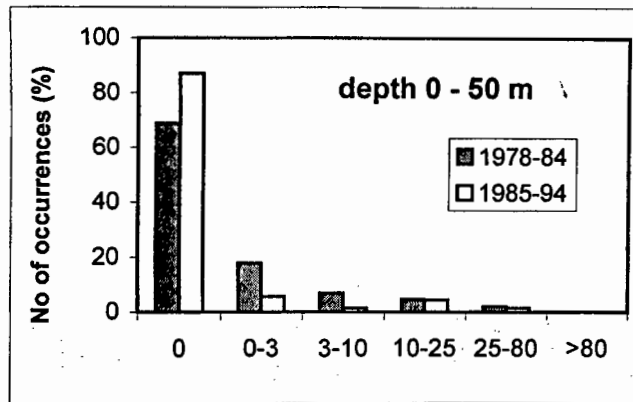


Fig. 3.19: Frequency distribution of the CPUE per drag, for 6 depth ranges and two periods: 1978 - 1984 and 1985 - 1994.

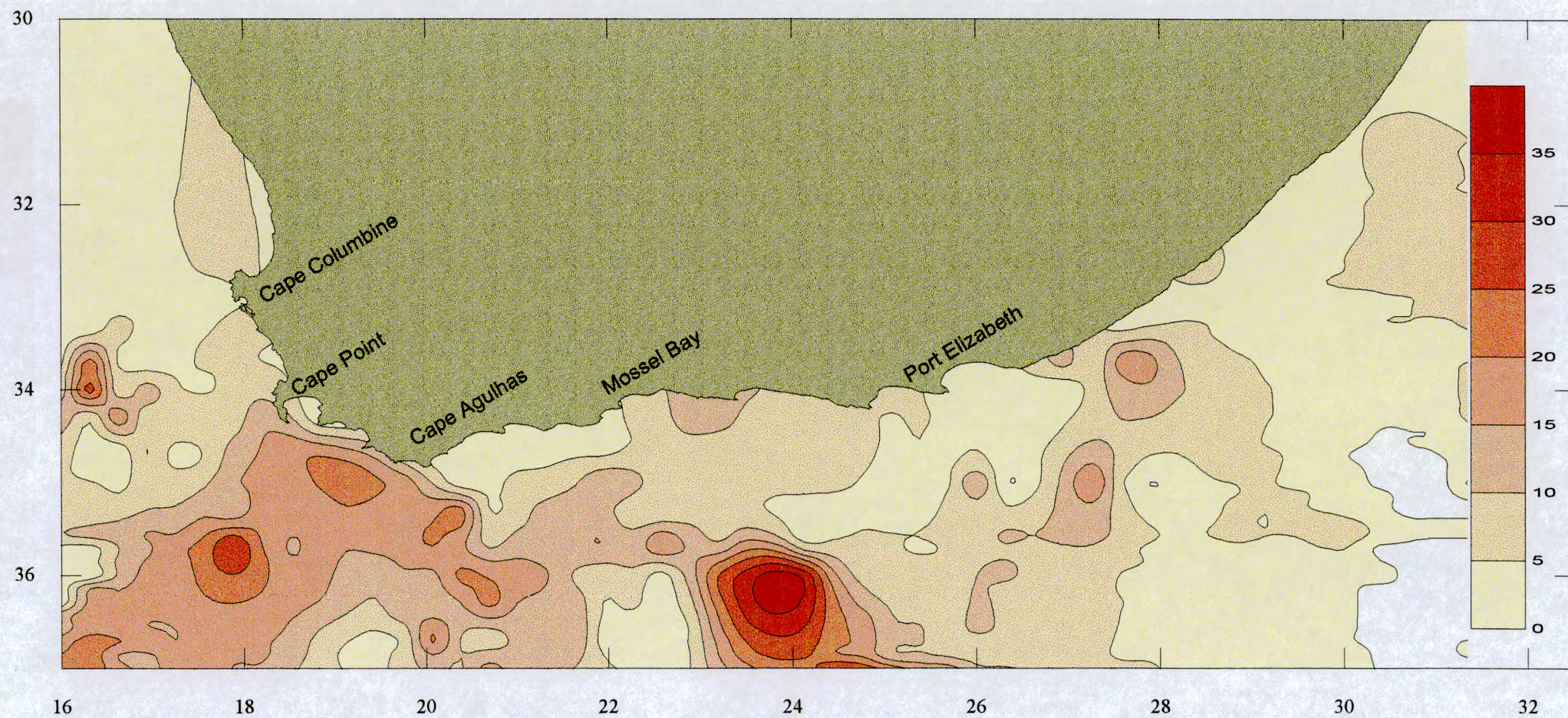


Fig 3.20a: Average trawl CPUE (kg/h) per 10' x 10' block 1978 - 1984

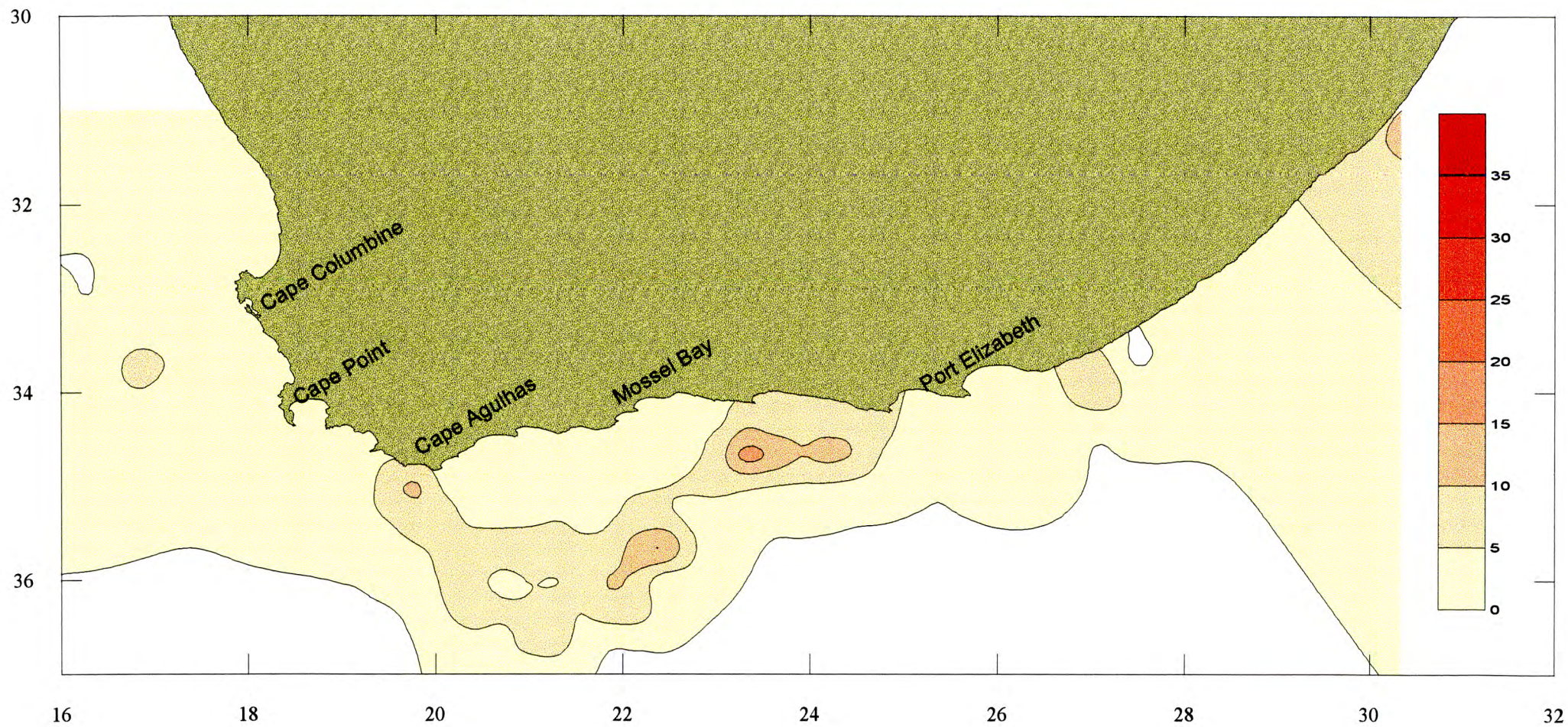


Fig 3.20b: Average trawl CPUE (kg/h) per 10' x 10' block 1985 - 1994

Possible differences between two periods (1978 – 1984 and 1985 – 1996) in the distribution of CPUE grouped in six 50-m depth categories were evaluated, and the results are shown on Figure 3.19. The percentage occurrence of zero catches was much lower in the early period than in the most recent one for the inshore interval and for intervals deeper than 150 m. The opposite trend is observed for the non-zero CPUE categories, particularly in waters deeper than 150 m, where the incidence of high CPUE values was higher in the early period. Differences over time in the distribution of the fishing fleet in relation to depth could be responsible, to some extent, for the observed declining trend in the annual CPUE (Fig. 3.10).

In order to examine the net effect of these different factors, which could have influenced the CPUE during the time period under consideration, average CPUE values calculated per 10 x 10 minute grid were plotted as a contour chart in Figures 3.20a and 3.20b for the same two periods. Only the data by drag were used, and therefore the second period excludes 1995 and 1996. Initial examination re-emphasizes the fact that average CPUE values were much higher in the first period considered than in the second. Also, these values were mainly offshore, in areas where there was little trawling in the second period, as shown in Figures 3.7a and 3.7b. The impact of the trawlers' withdrawal from areas of high CPUE on the overall CPUE depends on the frequency of those operations. In other words, if there was considerable trawling in areas of high CPUE in the early years, the sharp decline in annual CPUE after 1984 shown in Figure 3.12 could be the result of the trawlers moving away from those areas.

3.3. CONCLUSIONS

3.3.1. *The directed jigging fishery*

Most of the jigging boats in the early days of the fishery (the 1980s) were shorter than 10 m, whereas in the 1990s, the more mature phase of the fishery, there was a general trend towards the presence of bigger boats in the fleet. A tendency to increase the capital investment until such time as it becomes uneconomic is a feature of many industrial fisheries. In the case of the chokka fishery, the larger boats provide better accommodation for their crews than the skiboats, and therefore they are able to spend

longer periods at sea and to fish farther offshore, where chokka are found throughout the year. The net result of the gradual replacement of the small boats by larger ones has been an increase in the total time spent at sea, which translates to an increase in effort. Moreover, the larger boats are equipped with sophisticated processing facilities and can offer a better, more marketable product. Therefore, there is great incentive in this fishery to upgrade to freezer boats.

Although the total area exploited by the fishery has remained relatively constant since 1985, effort has increased in recent years between Port Alfred and Plettenberg Bay, while it has decreased in western areas such as in Seal Bay and False Bay. This trend could introduce biases into the annual CPUE time-series as an index of abundance, so unless they are estimated and adjustments made in an appropriate manner, CPUE trends could be reflecting changes in fishing patterns rather than changes in resource abundance. There is also likely that changes in efficiency/catchability (q) have taken place over time. However, q is assumed to remain constant in all the modelling approaches developed in the following Chapters.

Effort in the first half of the year, when there is little spawning activity of chokka, has been gradually increasing over time. This has happened as the freezer boats, which are equipped with facilities that allow them to catch chokka farther offshore on the feeding grounds, gradually replaced the skiboats, which are restricted to inshore operations on the spawning grounds. The net effect of these developments has been an overall increase in effort, as stated above, and a less pronounced seasonal trend in the catches in recent years.

3.3.2. *The trawl by-catch fishery*

The time-series of annual trawl CPUE for chokka shows an overall downward trend, with a sharp decline after 1983. This finding is consistent with the perception of the trawlermen that the quantity of chokka available to trawlers decreased substantially after the onset of the jig fishery (C. A. Atkins, General Manager, Seafood Division, Irvin & Johnson Ltd, pers. comm.). In order to get a better understanding and hence interpretation of the trawl fishery data used for this study, the distribution

of fishing effort was investigated both temporally and spatially. In addition, the distribution of the CPUE, computed at both the drag and the daily level (depending on year), was studied to evaluate the effects of changing fishing patterns, rather than changes in resource abundance, on the annual CPUE trend.

Over the full period considered, most of the drags were performed between Cape Agulhas and Port Elizabeth. For the same period, the largest portion of the effort, about one-third of the drags, took place between 50 and 150 m deep. These geographical parameters correspond to the area of operation of the inshore and offshore fisheries off the South African south coast. A contraction of the trawling area has taken place over time as a result of the trawlers withdrawing from some of the grounds farther offshore. Examination of Figures 3.7a and 3.7b suggests that the effort expended on those grounds was small, possibly having little impact on overall CPUE. In addition, examination of the frequency distribution of trawls per depth range shows differences in fishing patterns between the years prior to and after 1982. The influence of these changes on the CPUE, both contraction of the fishing grounds over time and changes in fishing patterns in relation to depth, needs to be evaluated by means of GLM.

There are no obvious seasonal trends in fishing effort, but there is generally less effort from April to September, in other words in winter, when adverse weather conditions are more prevalent.

Drags in which chokka contributed more than 50% of the catch seem to constitute only a small percentage of the total number made, most of those having taken place in 1979 and 1983. Those drags could be seen as chokka-directed and therefore there could be a case for eliminating them from the analysis performed in Chapter 4. Even so, given their overall infrequent occurrence, changes in the incidence of directed catches over time could have had only a small impact on the general annual CPUE trend.

Comparison of the CPUE frequency distribution between two periods, 1978 – 1984 and 1985 – 1996, reveals marked differences in the relative occurrence of zero catches of chokka, and in the relative frequency of high CPUE values. The percentage of

zero catches is clearly higher in the more recent period, particularly off the West Coast and in water deeper than 150 m. This could be an indication of a contraction in the resource distribution that is often a sign of a decline in general abundance as documented by Lluch-Belda *et al.* (1989) for various stocks of anchovy and sardine.

CPUE values were high on the offshore fishing grounds, where little trawling has taken place since the early 1980s. This situation could potentially have had a large impact on the overall CPUE trend, if those grounds were heavily fished at the time. However, it appears that only a small number of trawls took place on those sites, possibly having little impact consequently. A quantitative assessment of the effect is provided by the GLM analysis of the next Chapter. The highest incidence of large CPUE values was in the early period on the fishing grounds between Cape Point and Cape Agulhas, and for water depths between 150 and 200 m deep. That region is a long way from the grounds traditionally believed to be where chokka spawn, indicating that chokka tend to be caught by trawlers either during their migration towards the inshore spawning grounds or while dispersing after spawning (if indeed they do disperse). Clarifying these mechanisms is important to be able to model the resource and the fishery dynamics in a more realistic manner.

A more rigorous analysis of the factors influencing the trawl CPUE is undertaken in Chapter 4 within the statistical framework of General Linear Modelling (GLM).

CHAPTER 4

ANALYSIS OF THE DATA AVAILABLE FOR MODEL-ESTIMATION PROCEDURES

Some measure of abundance or, at least, of changes in abundance, is vital for any stock assessment study. Several such measures have been used in squid assessments. For example, the assessments of the two cephalopod stocks caught off the Falkland Islands, *Loligo gahi* (Agnew *et al.* 1998) and *Illex argentinus*, based on Delury depletion models (Beddington *et al.* 1990, Rosenberg *et al.* 1990, Basson *et al.* 1996), made use of indices of stock abundance derived from CPUE data. For the North West Atlantic, Brodziak and Rosenberg (1993) also used CPUE as an index of abundance to assess the squid stock. Lange (1991) investigated the use of spatial dispersion indices as an alternative to mean catch-per-tow indices of abundance provided by research vessels to predict stock availability in the fishery for longfin squid *Loligo pealei*, also a short-lived, migratory and schooling squid. In contrast, Montevecchi (1993) attempted to provide a short-term index of inshore availability of the short-finned squid *Illex illecebrosus* based on the proportion of squid eaten by gannets.

Catch per unit effort (CPUE) is often used as an index of stock abundance because it is difficult or costly to obtain direct measures of stock abundance by means of research surveys. Obtaining reliable estimates of catch per unit effort (CPUE) from the commercial fishery is usually therefore one of the first steps taken in a fishery study as a prerequisite to a resource assessment. There are cases, however, where CPUE does not provide a reliable estimate of abundance, for example in purse-seine fisheries or other fisheries, which target on aggregations. In such cases searching is highly efficient, so most effort is concentrated where fish are more abundant. As the stock is gradually depleted, the number of aggregations can decrease but the local abundance remains high. As a result, the CPUE stays high while the biomass drops. This type of non-linear relationship between CPUE and biomass is called hyperstability by Hilborn and Walters

(1992). However, unless a better estimate of resource abundance is available, CPUE can still be used provided the errors that may be introduced by the way in which CPUE may misrepresent abundance are taken into account in an appropriate manner (Gulland 1983).

One of the first problems faced when trying to relate CPUE to abundance is the standardization of fishing effort. A fishing fleet normally consists of vessels of different classes, and fishing efficiency will be related to features such as horse power or hold capacity, which define each category. The catch rate of a given vessel will be equal to the product of fish abundance on the fishing grounds in a particular year multiplied by the efficiency of the vessel or of the class into which it falls. Hilborn and Walters (1992) write this equality as:

$$U_{t,i} = U_{1,1} \alpha_t \beta_i \varepsilon_{ti}$$

where $U_{t,i}$ is CPUE at time t for vessel class i ,

α_t it is abundance in time t relative to time 1,

β_i is the efficiency of vessel class i relative to vessel class 1 and

ε_{ti} is a factor that accounts for the deviation between the observed U_{ti} and the expected value for t and i .

Taking logarithms of both sides, a linear model results, and the parameters of this model can be estimated using Generalized Linear Model (GLM) methods (Nelder and Mead 1975). The advantage of a GLM is that it provides a framework to incorporate other factors into the interpretation of CPUE, such as vessel attributes and spatial effects that could also be influencing the CPUE observed. These factors can then be included in the GLM model as long as they contribute significantly to the model's predictive ability. Moreover, the GLM provides the tools for determining the extent to which vessel attributes contribute to the catching power of a given vessel or vessel class. This may be particularly important in fisheries regulated by means of effort control. In the case of the chokka fishery, in which boats have frequently been upgraded, the ability to quantify the

contribution of various vessel attributes in terms of standard effort is essential to determine, for example, licensing conditions for upgrading.

The Generalized Linear Models were fitted using the procedure REG available in the SAS statistical package. REG uses the principle of least squares to produce estimates that are the best linear unbiased estimates under classical statistical assumptions (SAS/STAT User's guide, Release 6.03 Edition, 1988).

The four time-series of abundance indices used for the present study, with their particular advantages and problems in relation to their use as indices of abundance, are listed in Table 4.I.

Table 4.I: Features of the time-series used in the analysis

	JIG CPUE	TRAWL CPUE	AUTUMN Survey	SPRING Survey
POSITIVE FEATURES	Large data-set; can be related to spawner abundance. Data resolution daily	Longest time-series. Obtained from a by-catch fishery, so sampling of squid should be more random in relation to distribution than in a directed fishery. Covers most of the chokka distribution	Random stratified surveys. Since 1986 there has been at least one survey every year in spring or autumn. The methodology used has been consistent throughout the years	
PROBLEMS	Effort under-reported. No information on sounding or distance from the coast. No information on vessel features prior to 1995	Possible changes in fishing patterns and efficiency over time	Incomplete coverage of the resource distribution area. Possible increase in efficiency over time as a result of "learning from experience"	

Some of the problems, such as changes in fishing patterns, i.e. changes in the spatial distribution of the fleet, can be overcome by means of a GLM analysis as long as data on, for instance, catch position, are available. Other problems, such as possible increases in efficiency in the scientific surveys through learning, cannot be quantified and, although they may not invalidate the use of the data, they must be taken into account when results based on them are being interpreted. It has been a fact of these surveys that a large number of trawls used to result in broken nets and loss of the part of the catch when trawling on rocky substrates. Those substrates were identified and subsequently avoided resulting in some selection of smooth, sandy bottoms.

4.1 Index of abundance derived from the trawl by-catch fishery

4.1.1 Data and methods

Catch and effort

Catch and effort data from the hake fleet in the squid distribution area were extracted from the SFRI demersal data-base following the criteria listed in Chapter 3. Data extracted contain the following information:

- Company code
- Vessel code
- Landing date
- Drag date
- Drag duration (effort)
- Grid number
- Drag average depth
- Mesh size (mm)
- Target species
- Hake catch
- Declared species catch (all commercial species except hake) in kg
- Undeclared species catch (very few species not listed in the SFRI landing sheet) in kg
- Latitude

- Longitude
- Squid catch

The data base contains catch returns reported at the drag level which will be referred to as *drag-by-drag* data, and catch returns for which the effort was reported by drag, but the catch was accumulated throughout the day and reported against the last drag of the day. These data are referred to as *daily* data. Daily data can be used to compute an average daily CPUE per vessel; information on position and depth need to be averaged as well. The advantage of using drag-by-drag data is that there is no loss of information and potential outliers in the data can be identified at the drag level.

Data reported by drag and by day were identified at the time of extraction, and it was found that most data from 1978 to 1994 were reported by drag. Consequently, only data by drag were extracted from 1978 to 1994. A large proportion of 1995 and 1996 data was reported on a daily basis, so eliminating the daily data would have resulted in a substantial loss of information. It was therefore decided to use all the data for those two years and to compute an average daily CPUE as the ratio of the daily catch by the corresponding total daily effort. The corresponding water depth was recorded as the average for the day. The latitude, longitude and grid of the last trawl were assigned to the data for that day.

The majority of the drags (98%) refer to three target species only: hake, Agulhas sole and horse mackerel. Fewer than 1% of the drags were declared as having targeted chokka. However, some concern has been expressed about chokka-directed drags having been included in the data set and not having been reported as such. Therefore, a small proportion of drags containing >50% of chokka in the catch were identified; details regarding percentage incidence, location and temporal trends in these drags are reported in Chapter 3. Given the geographical location of those drags (see Chapter 3), made on traditional hake grounds of the South African trawl fishery (Japp *et al.* 1994), it is considered very unlikely that they were actually directed at chokka. As a result, they were not excluded from the analysis. However, given the years when most of those drags were made, late 1970s and early 1980s, they might

be seen as having influenced the apparent sharp decline in the trawl CPUE after those years. Therefore, sensitivity of the results from the GLM to eliminating those drags from the data set was tested. After identification and elimination of outliers, as described in the following section, CPUE was recalculated for consistency reasons as a daily average for the 1978-1994 data in the same manner as for 1995 and 1996.

Vessel attributes

Data on the attributes of the vessels that have operated in the hake and sole fisheries are available from Sea Fisheries. The attributes recorded are the following:

- Company name and code
- Vessel name and code
- Registration number
- Year of construction
- Period in which vessel was operational
- Vessel length
- Gross tonnage
- Propulsion capability/power (in hp and kW)
- Propeller (fixed or variable pitch)
- Kort nozzle (presence or absence)
- Winch power

A linear relationship has been demonstrated between landings-per-hour-trawled and vessel horse-power class for Canadian trawlers' landing Pacific cod (Westrheim and Foucher 1985). Brown (1998) performed a GLM of trawl data for the South African demersal fishery, to estimate an index of abundance for hake. She found a high level of correlation between certain of the characteristics associated with each vessel, and initially selected the vessel length to be included in the GLM standardization as an index of fishing power, since it was the piece of information that was most complete in the data base. For this reason, vessel length is also the chosen variable for the GLM analyses that follow (see section 4.1.3).

Examination of the vessel attributes file revealed that 20% of the vessels had variable pitch propellers and, of those, only 12% had a kort nozzle. All vessels with variable pitch propellers were longer than 42 m.

4.1.2 Identifying outliers in the drag-by-drag data before accumulation

Brown *et al.* (1996) identified several typographic errors and missing data when analysing the hake CPUE, and some of the criteria used in their study to detect those are also applicable to the chokka CPUE analysis. Records with the following characteristics were considered errors and were omitted:

- drags with positive effort, but zero catch (of any species);
- drags with effort values below the 1% quantile and above the 99% quantile (<60 or >390 minutes duration);
- drags with CPUE values above the 99% quantiles computed per year from the distribution of the CPUE per drag data;
- drags with missing data on date, mesh size, squid catch or total catch.

Drags corresponding to foreign vessels were eliminated as the possibility of them targeting on chokka was suspected.

4.1.3 The GLM model

The basic assumption made is that CPUE is proportional to squid abundance, but for this assumption to hold, effort from all the vessels should be standardized. The background on methods of effort standardization and the approach followed in this analysis can be found in Kimura (1981). The algorithm used to model the CPUE is

$$CPUE_{yij} = e^{(\ln(CPUE_{111}) + \alpha_y + \beta_i + \gamma_j + \varepsilon_{yij})} - \delta$$

where $CPUE_{111}$ corresponds to the catch rate in year 1, location 1 and vessel attribute 1,

α_y represents abundance in year y relative to year 1,

β_i represents the abundance in location i relative to location 1,

γ_j represents the effect of a vessel having attribute j instead of attribute 1, and

ε_{yij} is the residual for the year y , location i and vessel attribute j .

The factors considered were location factors, such as water depth, target species, season and area in which the trawl was made and vessel attributes such as total length, presence or absence of a koft nozzle and type of propeller. The greek letters correspond to the regression coefficients, except for δ , which is the constant added to the CPUE data to be able to deal with the zeros at the time of the log-transformation.

From the equation, it is evident that CPUE is assumed to be related to average abundance during the corresponding year (year-factor) as well as to factors that affect catchability (vessel characteristics, and time and position of the trawl). By including these factors in the model, their relationship with CPUE can be determined. This is done by taking logarithms of both sides of the equations and performing a multiple linear regression. Year abundance indices similar to adjusted CPUEs can be estimated directly from the regression. The rationale for log-transformation is the assumption of log-normality of residuals, i.e. that the logs of the residuals are independent and normally distributed, and that they have constant variance. Gulland (1956) gives empirical evidence that logarithmic transformation normalizes CPUE data and stabilizes its variance.

Variables such as vessel length and mean depth of the drag were initially treated as continuous. However, inspection of the associated residuals suggested that their treatment as discrete Boolean variables could allow better fits, because there were no clear linear relationships between the continuous variables and the catch rate. The relationship between catch rate and vessel length was therefore modelled by estimating a separate factor for each length-class of 5 m.

Variable selection

Standard statistical model selection procedures include or exclude factors based upon their statistical significance. However, in cases such as this with a very large data set, factors can be significant but of minimal effect, and the evaluation of significance itself rests on assumptions of independence of data which, in all likelihood, are correlated to some extent. To overcome the problem, the approach followed in this study was to add a group of Boolean variables related to a particular feature one at a time and then to make a decision on whether to include the group or to exclude it from the model, depending on its effect on the coefficient of determination, R^2 , i.e. only groups making a relatively large contribution to R^2 are retained.

The Boolean variables considered were related to the following features:

- vessel length: each Boolean variable corresponds to a 5-m length category, starting with <10 m;
- type of propeller (fixed or variable);
- presence or absence of kort nozzle;
- area where the drag took place: West Coast, Cape Point - Cape Agulhas, Cape Agulhas - Port Elizabeth, East of Port Elizabeth;
- depth where the drag took place: the Boolean variables correspond to 50-m intervals between 0 and 300 m depth;
- season when the drag took place: corresponding to three-month periods, i.e. January-March, April-June, July-September, October-December;
- target species as declared by the skipper, i.e. hake, sole, horse mackerel or "others";
- offshore grid: a Boolean variable identifies the drags that took place in deep water off the eastern Agulhas Bank during the early years of the period considered in this study (see Chapter 3).

Results from the inclusion of different groups of variables in steps are presented in Table 4.II.

Table 4.II: Results from a stepwise procedure for variable selection.

Model: $\ln(CPUE + \delta) \sim$	R^2
\sim year+vessel length	0.1102
\sim year+vessel length+propeller	0.1123
\sim year+vessel length+kort nozzle	0.1120
\sim year+vessel length+area	0.1397
\sim year+vessel length+area+depth	0.1800
\sim year+vessel length+area+depth+season	0.2046
\sim year+vessel length+area+depth+season+offshore grids	0.2046
\sim year+vessel length+area+depth+season+target species	0.2125

Vessel attributes, such as the type of propeller and presence or absence of a kort nozzle, had a minimal or no effect on R^2 and therefore were not retained in the final model; “offshore grid” was excluded for the same reason. Therefore, the variables retained in the model are vessel length, the area and depth where the drag took place, the season, and the target species.

Specifying the parameter δ

A constant, symbolized by δ , is added to the CPUE in order to be able to take the logarithm in cases where CPUE is equal to zero. In similar work carried out at ICCAT (International Commission for the Conservation of Atlantic Tunas), a value of δ of 0.1 times the mean CPUE was recommended. Brown (1998) in her application of GLM to hake data, based the selection of δ on the normality of the residual distribution obtained from the model fit. In this study, the regression was run for three values of δ to decide on which provided a residual distribution closest to normal. A value of *skewness*, which is a measure of the tendency of the residuals to be larger in one direction than in the other, and is defined as the expected value of the cubed of the deviations from the population mean, divided by σ^3 :

$$Skw = E(x - \mu)^3 / \sigma^3$$

as well as of *kurtosis*, which assesses the shape of the distribution considering the fourth power of the deviations from the mean (Zar 1984), were calculated for each value of δ .

δ as a factor of mean CPUE	0.05	0.010	0.005
<i>skewness</i>	0.506	0.315	0.261
<i>kurtosis</i>	-0.50	-0.885	-0.99

In a perfectly normal distribution, the skewness and the kurtosis should equal zero. In spite of the fact that none of the distributions of the residuals were completely normal, the value of δ of 0.05 times the average CPUE (average CPUE = 5.05) was considered the one that provided the best trade-off in relation to the two measures considered and was closer to the criteria adopted by ICCAT; therefore, it was used in the analysis.

4.1.4 Results

The R^2 value associated with the full model was 0.2125. The F value used to test the null hypothesis (H_0) that all coefficients in the model, except the intercept, are zero was equal to 1 004.48. The probability of obtaining a value of $F \geq 1 004.48$ by chance alone, if in fact H_0 was true, was 0.0001 (DF: Model = 47; Total = 174 985). Therefore H_0 can be rejected.

The parameter estimates from the multiple regression and associated statistics are listed in the Table 4.III:

Table 4.III: Parameter estimates and associated statistics from a GLM applied to the trawl CPUE data.

Variable	Parameter estimate	Standard Error	T for H0: Param.=0	Prob > T
Intercept	-0.7238	0.0880	-8.223	0.0001
1979	0.1338	0.0249	5.372	0.0001
1980	-0.3462	0.0242	-14.298	0.0001
1981	0.1048	0.0247	4.234	0.0001
1982	-0.1916	0.0254	-7.534	0.0001
1983	-0.4373	0.0252	-17.323	0.0001
1984	-0.5481	0.0247	-22.215	0.0001
1985	-0.5924	0.0249	-23.761	0.0001
1986	-0.8868	0.0245	-36.240	0.0001
1987	-1.0909	0.0245	-44.562	0.0001
1988	-0.8721	0.0245	-35.569	0.0001
1989	-0.6245	0.0255	-24.485	0.0001
1990	-1.0815	0.0252	-42.835	0.0001
1991	-1.0534	0.0256	-41.204	0.0001
1992	-1.3482	0.0256	-52.599	0.0001
1993	-1.2252	0.0269	-45.476	0.0001
1994	-1.0540	0.0265	-39.815	0.0001
1995	-1.1806	0.0274	-43.105	0.0001
1996	-1.1739	0.0282	-41.584	0.0001
Season:				
Apr-June	-0.5307	0.0106	-49.942	0.0001
July-Sept.	-0.6175	0.0105	-58.882	0.0001
Oct-Dec.	-0.0561	0.0105	-5.330	0.0001
Boat length(m)				
10-14	-0.1421	0.0825	-1.722	0.0851
15-19	0.0919	0.0822	1.118	0.2635
20-24	0.8851	0.0852	10.385	0.0001
25-29	0.1529	0.0847	1.805	0.071
30-34	1.2257	0.0888	13.809	0.0001
35-39	0.9570	0.0849	11.277	0.0001
40-44	0.8366	0.0844	9.908	0.0001
45-49	1.1370	0.0920	12.354	0.0001
50-54	1.1044	0.0907	12.180	0.0001
55-59	0.6896	0.0847	8.139	0.0001
60-64	1.3787	0.0953	14.468	0.0001
65-69	1.1113	0.0899	12.366	0.0001
70-74	-0.4566	0.1098	-4.157	0.0001
75-79	0.3476	0.0887	3.918	0.0001
80-84	0.8884	0.1105	8.039	0.0001
85+	0.5388	0.1001	5.381	0.0001
Area:				
C.Point-C.Agulhas	0.8803	0.0185	47.485	0.0001

C.Agulhas-P.Elizabeth	0.6315	0.0158	39.935	0.0001
East P. Eliz.	0.1974	0.0210	9.414	0.0001
Depth:				
50-100m	1.0100	0.0304	33.215	0.0001
100-150m	1.4212	0.0288	49.374	0.0001
150-200m	1.1283	0.0287	39.293	0.0001
200-250m	0.5255	0.0256	20.549	0.0001
250-300m	0.0576	0.0249	2.313	0.0207
Target sp:				
Sole	-0.4732	0.0120	-39.594	0.0001
H mackerel	-0.1905	0.0188	-10.142	0.0001
Others	-1.1096	0.1044	-10.631	0.0001

The intercept corresponds to boats between 5 and 10 m long, to West Coast operations shallower than 50 m and targeting on hake, from January to March 1978. The implication is that the predicted squid CPUE for a boat operating under those circumstances is $0.23 \text{ kg/h}(\exp^{\text{intercept}} - 0.05 * \overline{CPUE})$. Alternatively, the predicted CPUE of a 50 m vessel operating between 100 and 150 m, all the other conditions remaining the same, is 5.8 kg/h.

All parameter estimates are significantly different from zero at the 5% level, except for those related to 250-300 m depth and for three boat-length classes, which are not. Examination of the regression coefficients indicated that the 60 - 64 m vessel category is the most efficient, and that highest catch rates are obtained in the area between Cape Point and Cape Agulhas, during the first three months of the year and between 100 and 150 m deep when targeting hake. These results confirm the indications presented in Chapter 3. With the exception of the vessels 20-24 m long, the coefficients for vessels <30 m seem to be not significantly different from the intercept which relates to vessels 5 to 10 m long. The 70-74 m vessel category represents only two vessels, which operated in different periods. Most of the drags were made by one of the vessels which operated towards the edge of the maximum abundance of chokka (deeper than 150 m), hence giving a relatively low vessel factor (see Table 4.III). Further, CPUE falls rapidly for depths >200 m, beyond which the continental shelf starts.

A time-series of predicted CPUE under the most frequent conditions: a 50 - 55 m vessel operating between 100 and 150 m deep, is shown on Figure 4.1 together with the time-series of nominal trawl CPUE. It is interesting that the model predictions show the same abundance in 1979 and 1981, unlike the nominal CPUE, and show slightly less pronounced fluctuations from 1983 onwards. As a sensitivity test the GLM was also run, eliminating from the data those drags with >50% chokka in the catch. The resulting time-series is plotted in Figure 4.2 and shows a very similar trend to that produced including the same data. The percentage change in abundance per year derived from regressing the logarithm of the model prediction against time, is 7.7%.

4.2 CPUE data from the jig fishery

An index of abundance based on monthly CPUE data from the jig fishery is used in this study to assess the chokka resource. A full description of how this index was derived is given in Chapter 3. The index is expressed as kg/man/h, and can be described as the average catch per hour taken by a jig fisher (in a particular month). It can easily be argued that other factors, such as vessel attributes and area of operation, could be influencing the CPUE and should be taken into account. Only information on vessel length is available for all the boats that operate or have operated in the fishery. However, this information is not available in the form of a relational data base. Therefore, if a vessel has been replaced by a vessel of different size, it will not be possible to relate all the CPUE data to the correct vessel attributes.

A questionnaire was sent to all the jig boat owners in 1989 to collect information on the following boat attributes:

- length
- presence or absence of deck
- year of construction
- hull material

- type of hull (mono or double)
- engine (in-board or out-board).

In order to improve the interpretation of the jig CPUE in the years 1995, 1996 and 1997, questionnaires addressing the same questions, plus some additional ones, were attached to the permit application forms to be submitted annually to Sea Fisheries by October. The level of response has improved over time. However, of the vessels listed in 1996, 30% did not complete the questionnaire, although this figure does include boats that did not renew their application in that year. The additional information requested was:

- lights, i.e. quantity and power
- cooling/freezing facilities.

4.2.1 GLM analysis using two years of data

A GLM analysis was undertaken using 1995 and 1996 CPUE data and the corresponding date and position in relation to the coast. The total number of records used in the analysis was 17 973, after eliminating the observations containing missing data.

The model

$$CPUE_{mij} = e^{(\ln(CPUE_{1111}) + \zeta_y + \alpha_m + \beta_i + \gamma_j + \omega_{ym} + \epsilon_{mij})}$$

where $CPUE_{1111}$ corresponds to the catch rate in year 1, month 1, area 1 and vessel attribute 1,

α_m represents abundance in month m relative to month 1,

β_i represents the abundance in area i relative to area 1,

γ_j represents the effect of a vessel having attribute j instead of attribute 1,

ω_{ym} represents the year-month interaction, and

ϵ_{mij} is the residual for the area i , month m and vessel attribute j .

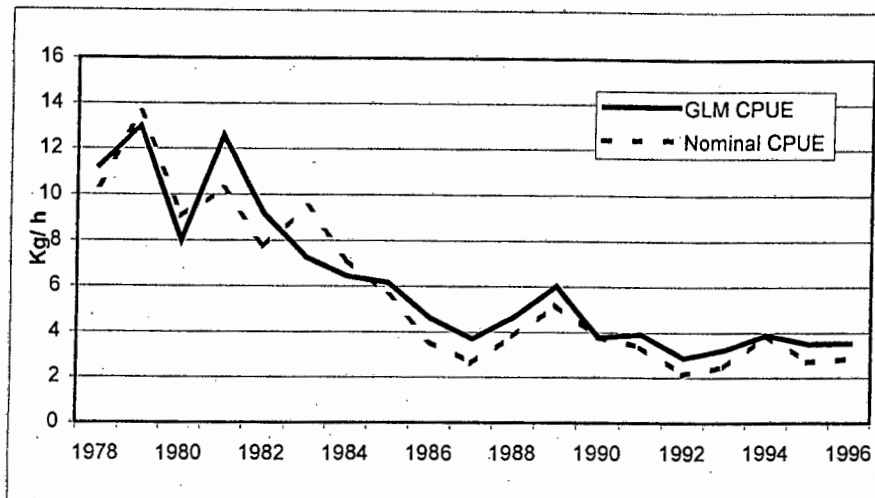


Fig. 4.1: Nominal and standardised trawl CPUE from the GLM analysis

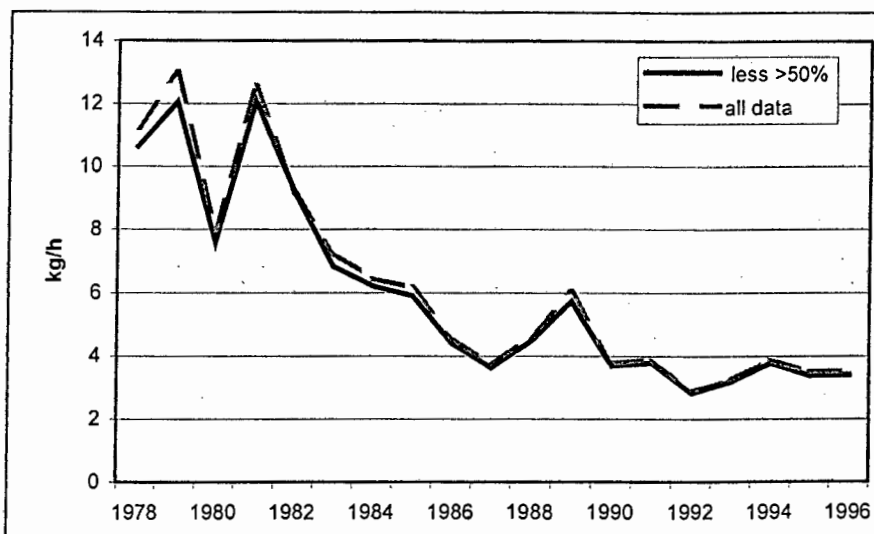


Fig. 4.2: Trawl time-series obtained from GLM based on 1) all the data, 2) eliminating the drags with more than 50% chokka in the catch.

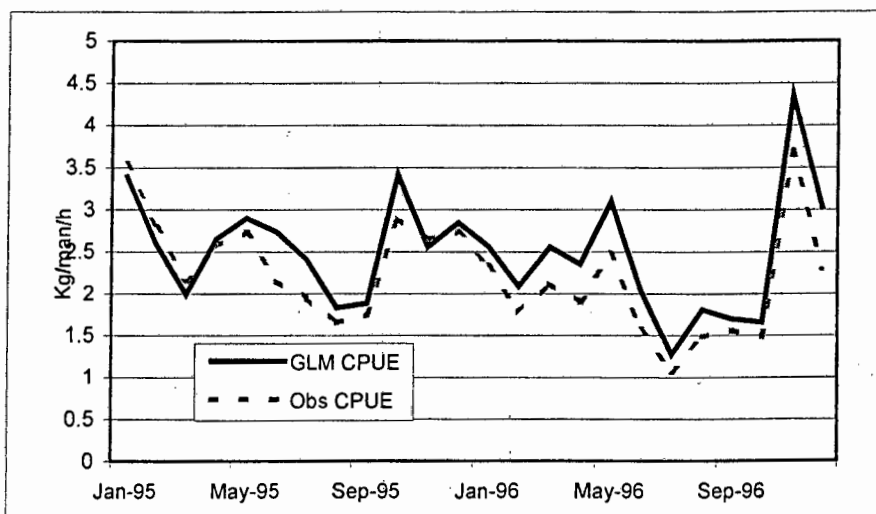


Fig. 4.3: Nominal and standardised jigging CPUE from the GLM analysis

Variable selection

The model includes year and month abundance factors and interactions per year-month. The reason for including these interactions is that the monthly pattern of abundance may not be the same from year to year. The year and monthly factors (including the interactions), the area factors and the vessel attributes were treated as Boolean variables. The CPUE data contain no zeros, and therefore in this case there was no need to add a constant δ value to the CPUE before taking the logarithm.

In order to select a model, a stepwise procedure was applied to evaluate the contribution of each variable or set of variables to the R^2 value, as in the previous section.

Table 4.IV: Stepwise procedure to select the variables to be included in the model.

Model: $\ln(\text{CPUE} + \delta) \sim$	R^2
Year+month	0.072
Year+month+area	0.089
Year+month+area+type of hull	0.094
Year+month+area+type of hull+hull material	0.103
Year+month+area+type of hull+hull material+boat length	0.133
Year+month+area+type of hull+hull material+boat length+deck+ in-board engine	0.136
Year+month+area+type of hull+hull material+boat length+deck+ in-board engine+ No light	0.136
Year+month+area+type of hull+hull material+boat length+deck+inboard engine + No light+freezing facility	0.141
Year+month+area+ type of hull+hull material+boat-length +deck+ inboard-engine+ No light+freezing facility+year-month interactions	0.166

The results shown in Table 4.IV indicate that there is little gain in including the vessel attributes in the model. However, given the fact that only two years of data could be used at this stage of the collection of information on vessel attributes, it would be premature to decide to remove them totally. In addition, there is merit in examining the values and significance of the corresponding regression coefficients.

4.2.2 Results

The R^2 computed is 0.166, indicating that only a small portion of the total variation in the data is explained by the regression. The F value of 80.98 was highly significant, with an associated p value of 0.0001, indicating that at least some of the coefficients in the regression are significantly different from zero. Therefore the null hypothesis that they all are equal to zero should be rejected.

Table 4.V: Results from the GLM analysis for 1995 and 1996 jigging CPUE data

Parameter	Estimate	Pr > T	Std Error of Estimate
INTERCEPT	1.2531	0.0001	0.0656
Year 96	-0.2799	0.0001	0.0440
February	-0.2676	0.0001	0.0547
March	-0.5333	0.0001	0.0504
April	-0.2443	0.0001	0.0529
May	-0.1569	0.0004	0.0443
June	-0.2147	0.0001	0.0474
July	-0.3442	0.0001	0.0492
August	-0.6158	0.0001	0.0479
September	-0.5872	0.0001	0.0442
October	0.0075	0.8656	0.0441
November	-0.2829	0.0001	0.0569
December	-0.1754	0.0001	0.0438
Port Alfred	0.2227	0.0001	0.0551
Algoa Bay	0.0327	0.4788	0.0462
Port Elizabeth	0.2093	0.0001	0.0449
Jeffreys Bay	0.0733	0.1091	0.0457
Tsitsikamma	0.1656	0.0006	0.0483
Plettenberg Bay	0.1035	0.027	0.0468
Mossel Bay	-0.0317	0.8471	0.1644
Still Bay	-0.0228	0.7803	0.0818
Hermanus	0.4266	0.0733	0.2382
Seal Bay	0.2324	0.0002	0.0615
False Bay	-1.8133	0.0001	0.2054
Double hull	-0.1148	0.0001	0.0185

Stainless steel	0.0210	0.4805	0.0298
Fibreglass	0.1476	0.0001	0.0232
Boat length(m)			
10-15	0.0328	0.6389	0.0699
15-20	0.0419	0.5658	0.0729
20+	-0.2068	0.0066	0.0761
Deck	-0.0869	0.0006	0.0253
Inboard eng	-0.3964	0.0001	0.0644
No lights	-0.2159	0.0001	0.0493
Freezing facility	-0.2600	0.0001	0.0269
Year96*February	0.0618	0.3846	0.0710
Year96*March	0.5311	0.0001	0.0668
Year96*April	0.1586	0.0222	0.0693
Year96*May	0.3460	0.0001	0.0615
Year96*June	-0.0195	0.7643	0.0650
Year96*July	-0.3576	0.0001	0.0670
Year96*August	0.2659	0.0001	0.0646
Year96*September	0.1761	0.0042	0.0615
Year96*October	-0.4438	0.0001	0.0614
Year96*November	0.8119	0.0001	0.0783
Year96*December	0.3411	0.0001	0.0604

The intercept corresponds to the CPUE of a type of skiboat (5 - 10 m boat, out-board engine, wood - mono hull, with lights), operating in January 1995, off East London. The predicted CPUE for such a boat operating under those conditions is 3.5 kg/man/h. Examination of the regression coefficients suggests that the smaller fibreglass boats are probably the most efficient. However, they do not have the same capability to operate under adverse weather conditions and to spend long periods at sea, which makes them economically less efficient than the larger boats. This could also provide an explanation of why the small fibreglass boats appear to be most efficient: it may be that they are fishing only under good/ideal conditions, in contrast to the bigger boats.

Nominal CPUE and the GLM-predicted CPUE for a skiboat with the features included in the intercept, and operating in the Mossel Bay area, are shown in Figure 4.3. The model estimates are generally above the nominal CPUE, but it must be remembered that the model prediction corresponds to a particular type of vessel and area, whereas the nominal CPUE represents an average across all areas and all the boats that carry between 4 and 20 men (see Chapter 3).

4.3 Biomass estimates from demersal surveys

4.3.1 Data

4.3.2

The shelf and slope of the Agulhas Bank, east of Cape Agulhas, are surveyed regularly by means of a semi-random stratified bottom trawl survey (as explained below) for the primary purpose of estimating hake biomass (Badenhorst and Smale 1991). Biomass estimates, based on the swept area method, of species such as *Loligo*, which are caught in the trawl, are also provided by these surveys. Badenhorst and Smale (1991) report that the area covered by the survey extends from 20 to 27°E and from 50 to either 200 or 500 m deep depending on the time of the year. The total area is divided into 100 m depth strata. Each stratum area is then divided into squares of 5 x 5 nautical miles. A number of squares proportional to the stratum area are selected randomly within each stratum and a trawl station is occupied in each of the squares selected. A target of approximately 100 stations is set for the survey, with an average of 4 - 6 stations being completed daily, dependent on weather conditions and steaming time between stations. Fishing takes place during full daylight, with the first trawl of the day commencing after sunrise and the last trawl being hauled before sunset. A standard German 180 foot net is used, and the codend is lined with 25-mm anchovy mesh in order to retain all small fish. The trawling time is generally 30 minutes.

The survey programme started on the South Coast in September 1986 (Payne *et al.* 1989). Since 1988, the surveys have generally taken place twice per year in autumn and spring (Table 4.VI). The surveys used in this study, as well as the estimates of chokka abundance and their CVs, are shown in Table 4.VI.

Table 4.VI: Estimates of chokka biomass and their associated CVs for the South Coast biomass surveys.

Year	Month	Chokka biomas (tons)	CV
1986	September	14 478	0.22
1987	September	11 992	0.14
1988	May	8 957	0.15
1989	May	18 976	0.22
1990	May	8 960	0.20
1990	September	13 410	0.14
1991	May/June	14 677	0.24
1991	September	23 480	0.17
1992	April	22 134	0.18
1992	September	10 018	0.14
1993	April/May	22 134	0.18
1993	September	14 396	0.17
1994	June	22 191	0.24
1994	September	15 368	0.15
1995	May	23 264	0.13
1995	September	14 961	0.13
1996	May	26 831	0.10
1997	April/May	94 46	0.10

The estimates of chokka biomass and their 95% confidence intervals from the autumn and spring surveys are plotted in Figures 4.4 and 4.5.

4.3.2 Examination of trends in the biomass estimates

Both time-series show an increasing trend in biomass from the time the surveys started to present, although the most recent data point in the autumn time-series (May 1997) is notably less than such trends would have predicted. The observed increase could be reflecting an increase in overall abundance, but changes over time in resource distribution or in fishing efficiency could also result in the trends. Possible artefacts of this nature that were investigated are:

1. Changes in the resource distribution:
 - a) the resource moving eastwards, into the area of the survey;
 - b) changes in vertical distribution.
2. Increase in efficiency:
 - a) skipper / fishing master learning process;
 - b) changes in equipment or techniques that could result in enhanced squid catchability.

1a) Chokka are distributed over part of the West Coast as well as the entire Agulhas Bank up to about 300 m deep, whereas the research surveys cover only part of this area. Therefore, an increase in biomass estimated by the surveys could be the result of a change in distribution rather than in overall abundance. In order to investigate this possibility, the estimated biomass per longitudinal stratum was plotted for the autumn and spring surveys (Figs 4.6 and 4.7).

Examination of Figure 4.6 (autumn surveys) suggests that the survey area covers a large portion of the main distribution of the resource as well as the tail of this distribution eastwards, but that it does not cover entirely the distribution towards the west. Features of the entire chokka distribution are discussed in Chapter 3. Nevertheless, examination of

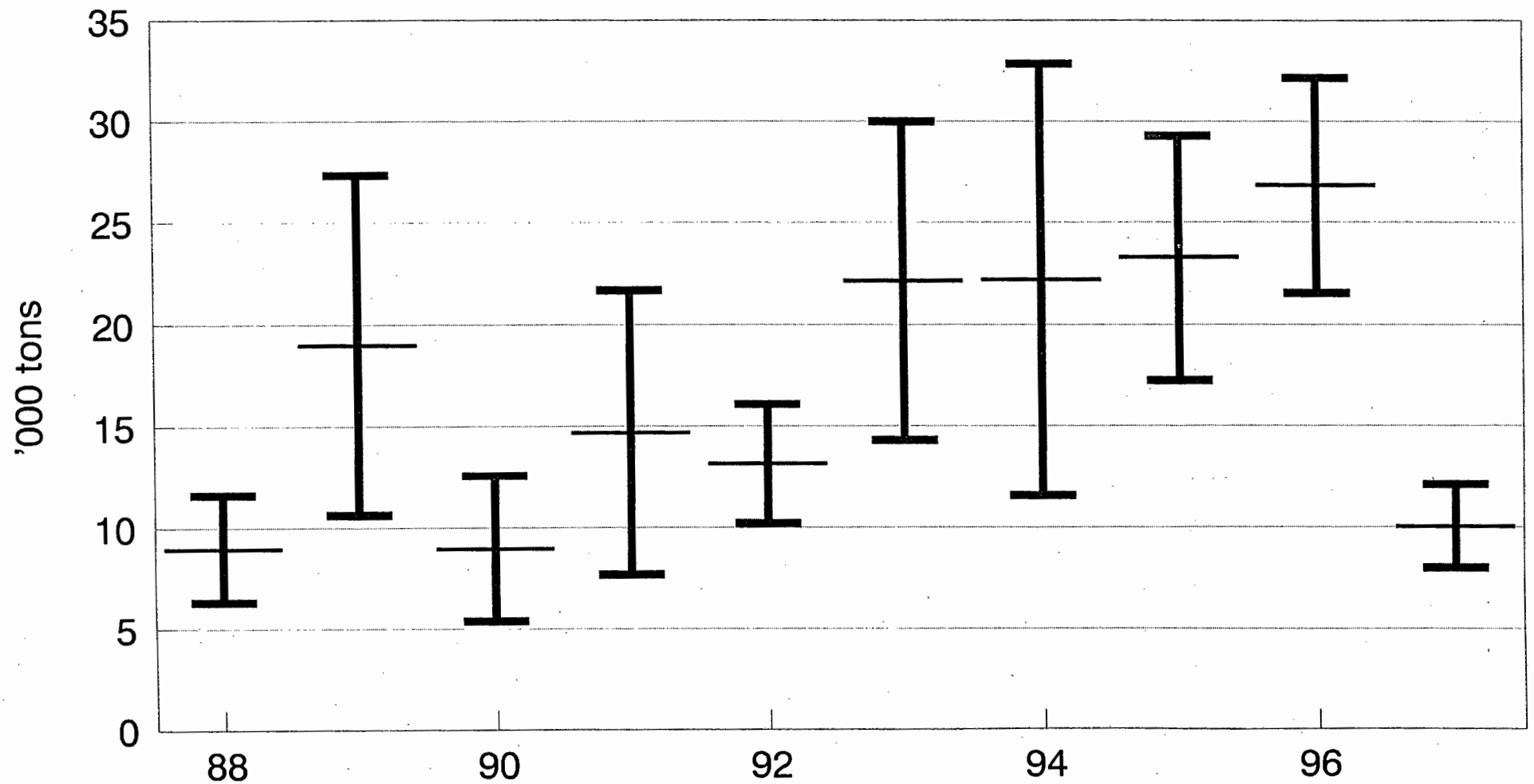


Fig. 4.4: Time-series chokka area-swept biomass estimates from the South Coast autumn demersal surveys (error bars correspond to 2 std. errors).

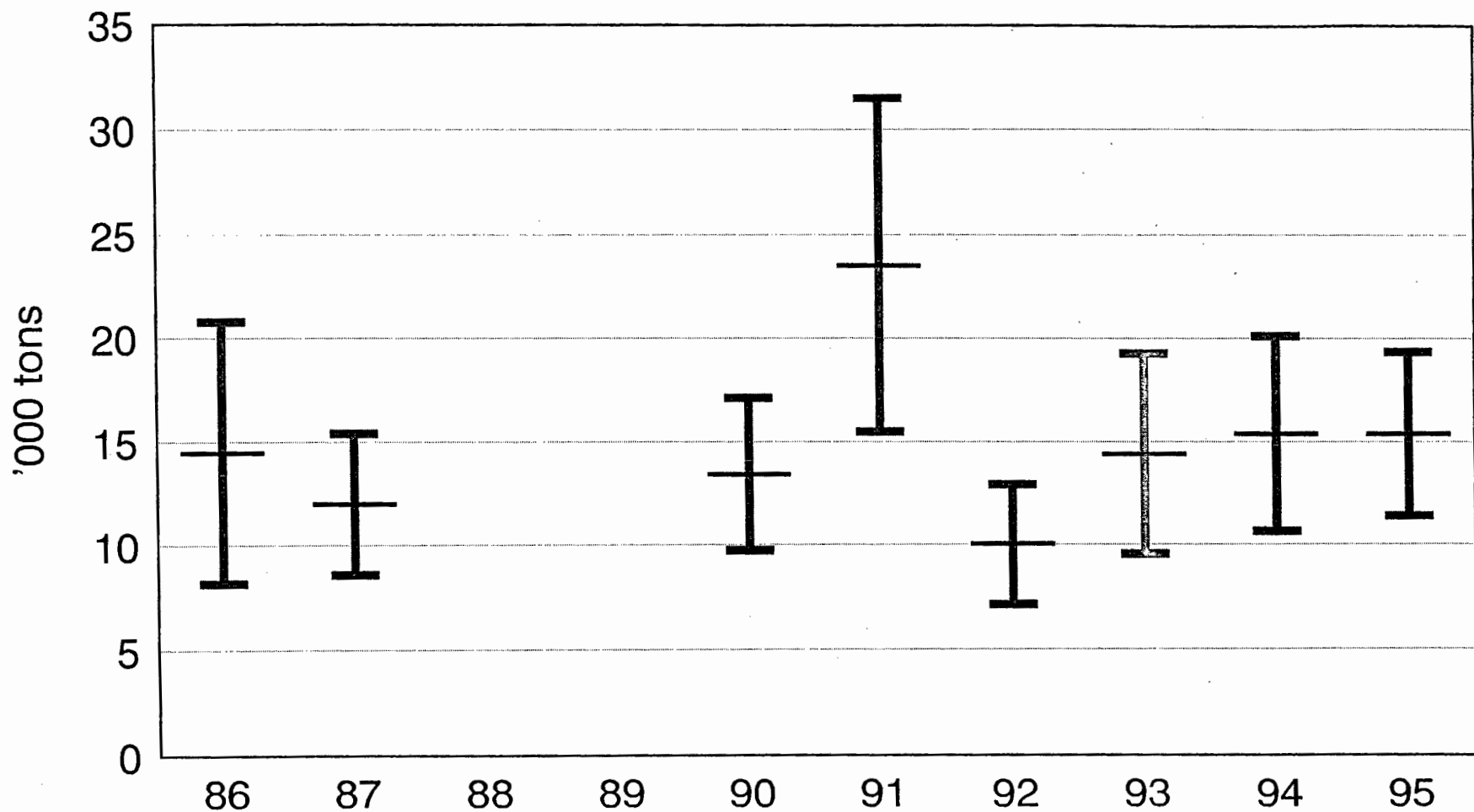


Fig. 4.5: Chokka area-swept biomass estimates from the South Coast spring surveys (error bars correspond to 2 std errors).

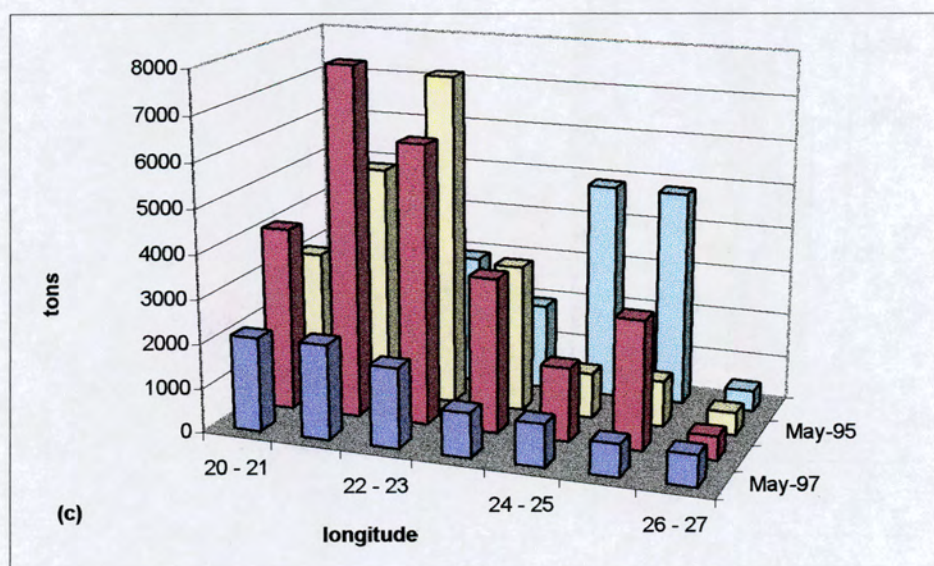
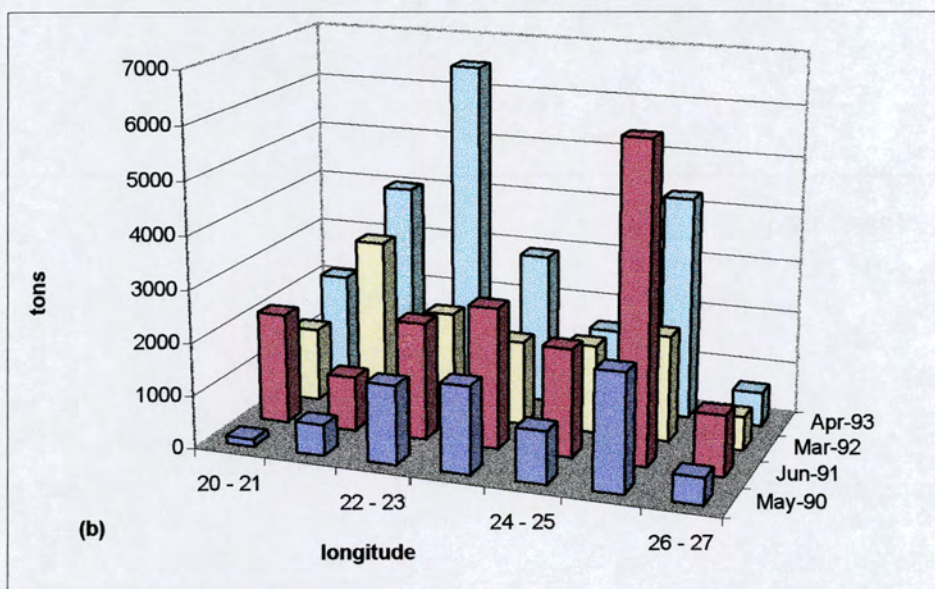
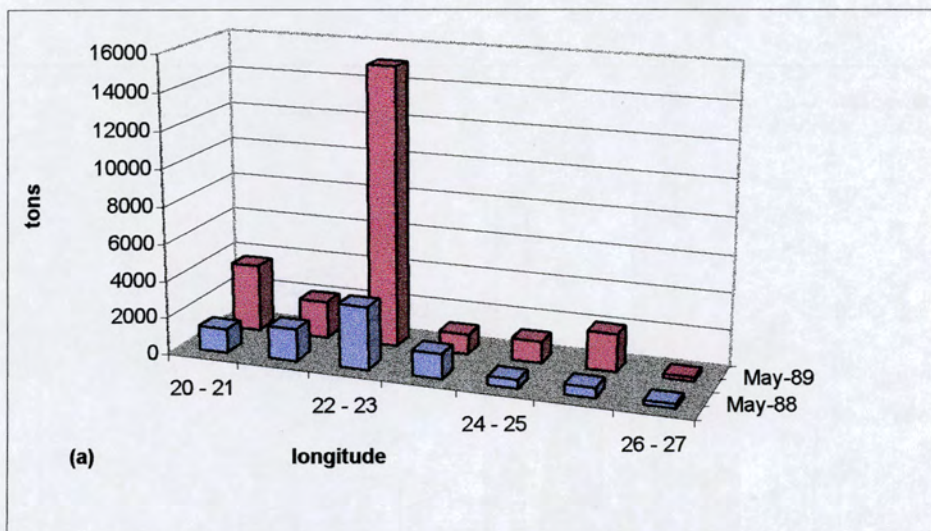
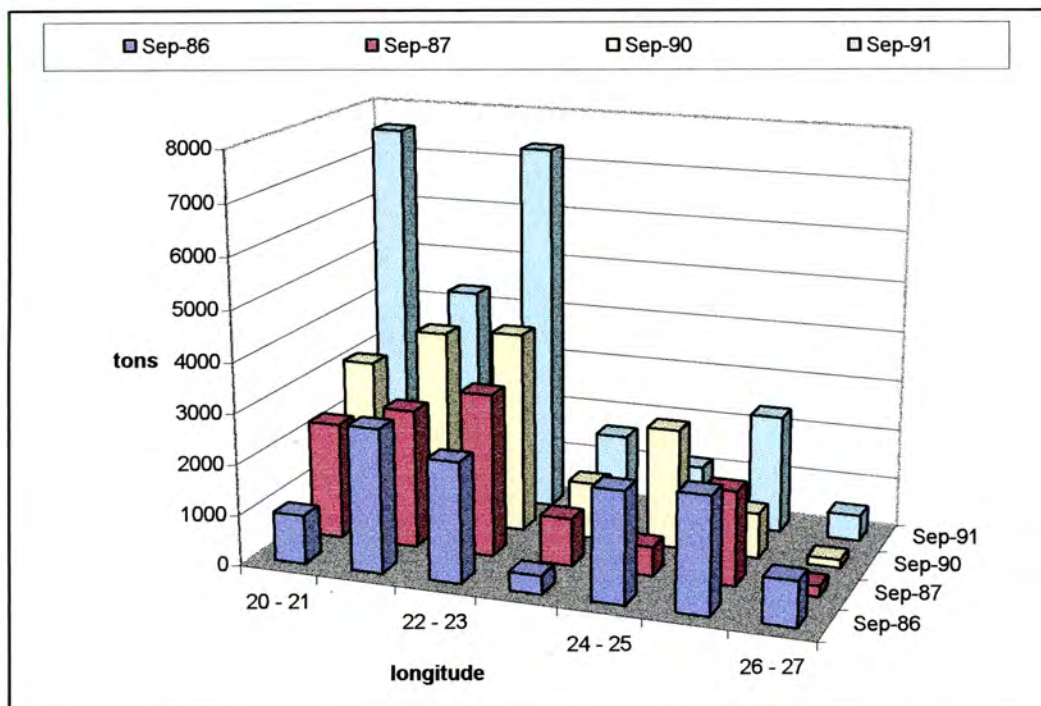
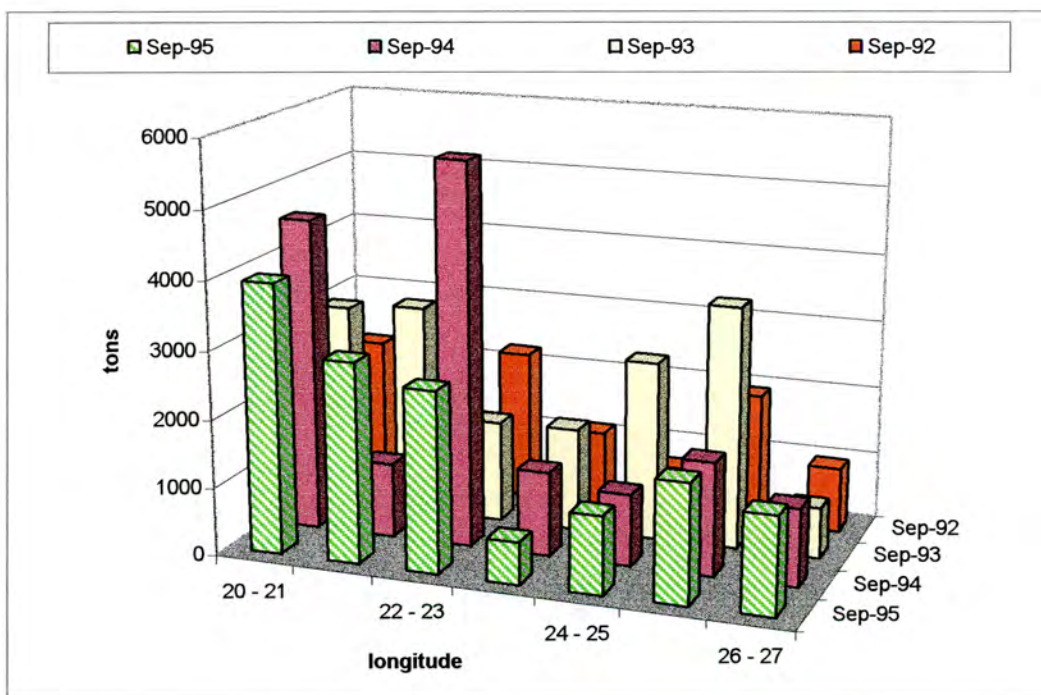


Fig. 4.6: Squid abundance per longitude stratum for the autumn surveys: a) May 1988, May 1989; b) May 1990, June 1991, March 1992 and April 1993; c) June 1994, May 1995, May 1996 and May 1997 (order inverted to show 1997 in the front).



a) Surveys 1986 - 1991



b) Surveys 1992 - 1995

Fig. 4.7: Biomass estimates per longitudinal strata from spring surveys

Figure 4.6 (a, b and c) and of Table 4.V indicates that it is the magnitude of the peaks rather than the position that explains the increasing trend in estimated biomass from the autumn surveys.

Maximum abundance is generally found between 21 and 23°E, i.e. in the vicinity of Mossel Bay.

The distribution per longitudinal stratum as estimated from the spring surveys (Figs 4.7a and 4.7b) shows a slightly different pattern from that shown by the autumn surveys. Generally there are two peaks in abundance, but there seems to be a third peak in the west during 1991 and 1994, years when the total estimated biomass was highest at that time of the year. It is unfortunate that no spring survey estimate is available for 1989, a year of high chokka biomass according to all the other indices.

Table 4.V: Longitudinal position of the maximum and minimum biomass estimates for the autumn surveys.

Longitude	May 88	May 89	May 90	Jun 91	Mar 92	Apr 93	Jun 94	May 95	May 96	May 97
20-21			Min.							
21-22				Min.	Max.				Max.	Max.
22-23	Max.	Max.				Max.		Max.		
23-24										
24-25							Max.			
25-26			Max.	Max.						
26-27	Min.	Min.			Min.	Min.	Min.	Min.	Min.	Min.

The difference in patterns of abundance between autumn and spring distributions is also evident in relation to depth strata, as is shown in Figures 4.8a and 4.8b for the three most recent autumn and spring surveys as an example. In autumn, the larger concentrations seem to lie between the 100 and 200 m isobaths, whereas the spring surveys detect large concentrations inshore of the 100 m isobath, as a result of the inshore migration of the

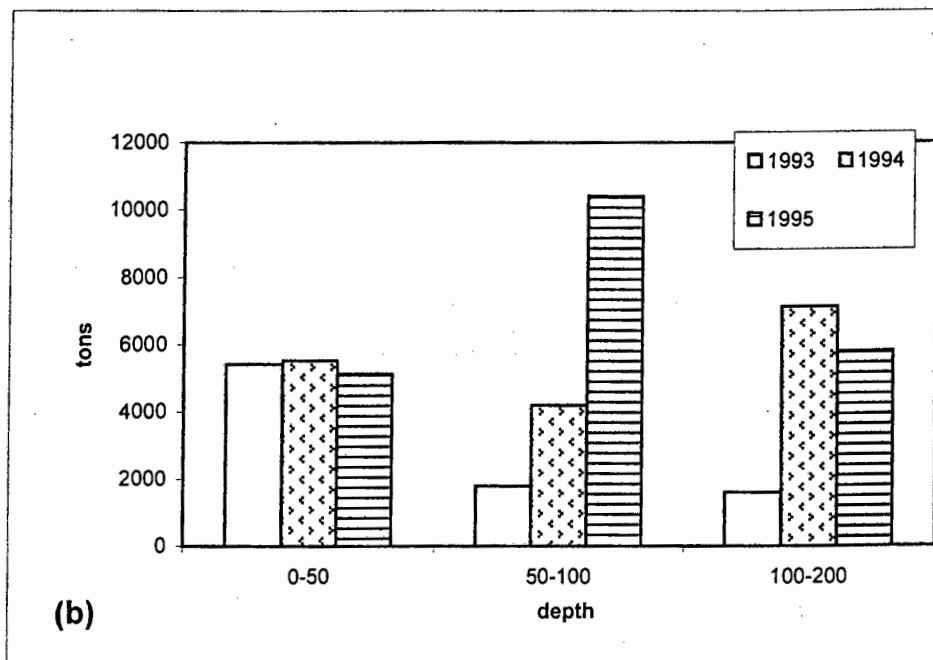
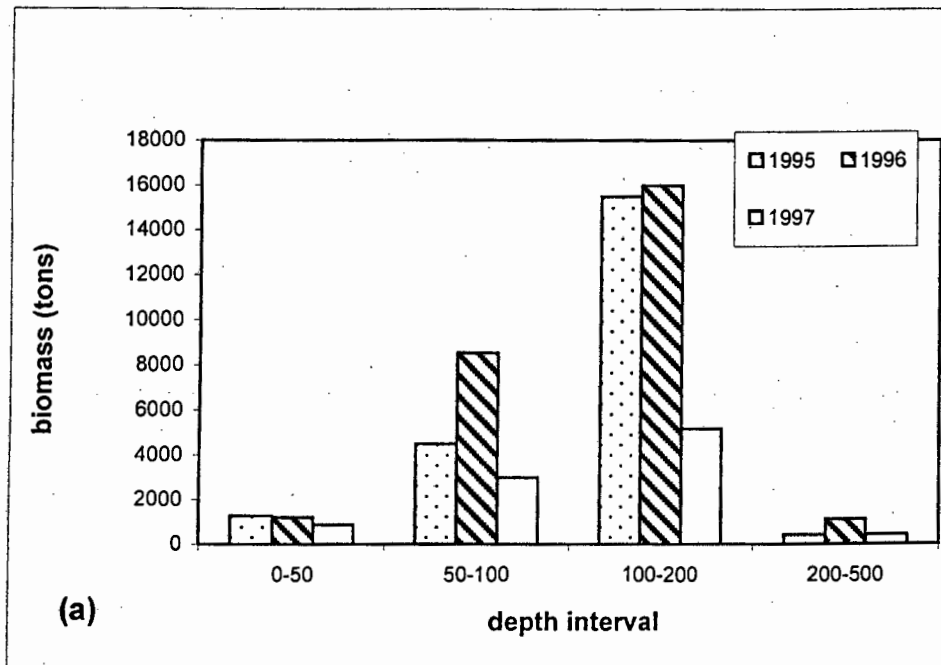


Fig. 4.8: Biomass per depth interval from (a) autumn surveys and (b) spring surveys.

chokka as they grow and mature. No clear evidence of a change in the distribution pattern over time emerges from examination of Figures 4.8a and 4.8b.

1b) Research on vertical distribution of chokka is not conclusive (Augustyn *et al.* 1993).

2a) In the early days of the surveys, there were many incidents of gear loss as a result of trawling in areas of rocky seabed. However, knowledge of the South Coast grounds increased through the years, and the non-trawlable areas can now be avoided as a result. Nowadays, the number of trawlable blocks has declined in comparison to earlier surveys, and so has the number of unsuccessful hauls, and this should result in more precise estimates of biomass. However, chokka spawn on sandy substrata and if, as seems likely, there has been a tendency for that type of ground to be selected, the area where the chokka squid do occur would have been progressively favoured by this change in survey procedure. This trend would have led to a change in the bias of the survey estimates as the overall area was less and less representatively surveyed.

2b) Bobbins were attached to the gear in the early years of the series. They have since been removed as knowledge of the grounds has improved. No other changes in basic trawling gear have been recorded.

4.4 Summary

1. The variables identified as being influential on the trawl CPUE are vessel length, area, depth and season when the drag took place, and target species.
2. Although the results indicate a correlation between the CPUE and the set of explanatory variables, a large portion of the variability in the trawl CPUE data (close to 80%) is not explained by the regression.
3. Examination of the regression coefficients indicates that the higher values of trawl CPUE are obtained in the first three months of the year, between 100 and 150 m deep and in the area offshore between Cape Point and Cape Agulhas.
4. The estimated trawl CPUE from the GLM analysis shows a decline from 1982 onwards

which is slightly less pronounced than that indicated by the nominal CPUE, but still indicates a 7.7% annual decline over the period investigated.

5. The application of a GLM to two years of monthly CPUE data from the jig fishery yielded a number of significant explanatory variables, but only a relatively small portion of the total variation in the data was explained by the regression.
6. The month when jigging took place, together with the boat length, are the factors that contribute most to explaining the data variability. The year-month interactions are relatively important factors, suggesting changes in monthly availability from year to year.
7. The depth at which jigging operations are performed could be influential on the jig CPUE, and it is therefore desirable that steps are taken to start collecting this information from the skippers as soon as possible.
8. The resource distribution off the South Coast in autumn appears to show a single peak in abundance. Although the peak and the remaining distribution towards the east are covered by the survey, the western part of the resource distribution is not.
9. Two (and sometimes three) peaks in the distribution are observed in years of large abundance in the area covered by the spring surveys. It is possible that, in years of high abundance, chokka distribution expands towards the west, resulting in greater than normal densities of chokka off the Western Agulhas Bank in spring. If that is true, the spring survey index would be an underestimate in years of high abundance of chokka.
10. Examination of the biomass distribution as indicated by the autumn surveys since 1988 and by the spring surveys since 1986 does not suggest that the resource has systematically moved into the survey area over time. Therefore, changes in resource distribution do not explain the increasing trend in resource abundance indicated by the surveys.
11. The resource biomass seems to peak between 100 and 200 m in autumn, whereas the larger concentrations are found inshore of 100 m in spring, coinciding with an inshore migration of chokka to spawn.

CHAPTER 5

Investigation on the effects of different levels of effort and of the closed season in the jig fishery for chokka squid *Loligo vulgaris reynaudii*

5.1 INTRODUCTION

Although annual chokka catches have not yet surpassed 11 000 tons, the jig fishery is one of South Africa's most valuable fisheries. Most of the catch is exported to Europe (mainly Italy and Spain), and the estimated wholesale value at first sale in 1995 was close to R104 million or US \$22 million in 1997 (Cochrane *et al.* 1997). The fishery is regulated by means of a closed season of variable length, and effort restrictions in the form of limits on the number of vessels and number of men on board. Furthermore, it is forbidden to catch chokka in the Tsitsikamma National Park (Fig. 1.1), where intensive spawning has been observed in the past. However, in spite of the fact that entry to the fishery was closed in 1987, there has been a subsequent creeping increase in effort, as measured by the numbers of hours man-fishing (Fig. 3.3). Together with this increase, there has been an expansion of the fishing grounds to cover areas farther offshore where adult squid are also found (G. Christy, South African Squid Management Industry Association, pers. comm.) After overall effort control, the most important management tool in the jig fishery is the closed season, which was first implemented in 1988. For the first three years of implementation the closed season was enforced for the whole of November, but since 1991 it has extended from about the last week of October to mid November.

In this Chapter, the effects on the stock of various levels of effort, both with and without a closed season, are modelled. In order to do so:

- a biomass dynamic model with monthly time-scale was developed;
- catch per unit effort (*CPUE*) was used as an abundance index;
- the sensitivity to model assumptions was evaluated;
- the impact on the resource of varying effort levels was projected.

The objective of the exercise is to use the information available about the fishery and what is known about chokka squid dynamics to assess the consequences of these factors for quantities that could be relevant to both the squid fishing industry and for managing the resource.

5.2 MATERIAL AND METHODS

5.2.1 Data

The data used for the study were the catches and corresponding effort from 1985, the year when the boat owners or skippers first submitted such data, until the end of 1996. The original data consist of daily records of catch in mass and effort expressed in terms of number of men on board multiplied by the hours spent at sea, which is roughly proportional to effective effort. Calculations of *CPUE* were based on data from boats carrying between 4 and 20 men on board; data from boats carrying more men were excluded. The rationale for this is that boats carrying more than 20 men have some involved in packing and handling and therefore that the boat's catch would no longer be directly proportional to the number of men on board. The time unit chosen for analysis was one month, which was considered suitable for the approach taken and given the relatively short life of chokka. The monthly effort data were averaged for each month from 1988 to 1995 to determine the monthly pattern of effort deployed in the fishery. This period was selected because the closed season was first implemented in 1988 and, although there has been an increase in effort since then, the assumption is made that the monthly effort pattern has not changed over the period. The monthly pattern of relative effort levels is indicated by the vector $\{\lambda_{\text{Jan}}, \lambda_{\text{Feb}}, \dots, \lambda_{\text{Dec}}\}$, where $\lambda_{\text{Sep}} = 1$, because September is the month in which most effort is applied.

5.2.2 Modelling the biomass on the spawning grounds

Given the sparseness of information available for the study, it was considered impossible to distinguish between the effects of natural mortality, emigration and somatic growth in the resource. The approach taken was therefore to aggregate these processes in a single parameter g , treated as an annual rate, which would account for their net effect

on the biomass. For this type of short-lived organism, the value of the instantaneous rate of natural mortality is expected to be high. For example, Beddington *et al.* (1990) used a value of 3 year^{-1} in their assessment of *Illex argentinus* around the Falkland Islands. Another possible scenario for chokka squid is low constant mortality while on the spawning grounds, followed by high mortality or emigration at the end of the spawning season. There has been much speculation about post-spawning mortality in chokka, such as has been found for other species of cephalopods, but it has not yet been documented. In contrast, dispersal after spawning and before death may be more prevalent in chokka (Augustyn 1990).

The association of egg capsules with the inshore runs of chokka, together with the fact that the state of maturity of the animals caught in the jig fishery indicates that they are either mature or, in the case of males, spent, give ample evidence that inshore presence in the study area is related to spawning migration (Augustyn 1990). Immigration to the spawning grounds seems to take place in the form of discrete runs (Augustyn 1990). Although this can take place year-round, there is normally one peak in spawning intensity, in spring and early summer, with a variable smaller peak in autumn or winter (Augustyn 1990, Sauer 1991). Monthly chokka squid catches from the jig fishery therefore reflect the changing abundance of chokka on the spawning grounds.

Immigration is modelled as a pulse arriving at the fishing grounds at the beginning of each month during the "spawning season", which takes place from May to December. The period selected was based on the decrease in the average mantle lengths (taken to reflect immigration of younger animals) observed in length frequency samples of the catches analysed by Sauer (1991). The expected monthly recruitment or immigration to the spawning grounds (I_m) is assumed to remain constant throughout the season and from year to year, i.e:

$$\begin{aligned} I_m &= I, \text{ for } m = 5 \dots 12 \\ I_m &= 0, \text{ for } m = 1 \dots 4 \end{aligned} \quad (5.1)$$

Brodziak and Rosenberg (1993), in their model of the inshore *Loligo pealei* fishery off Cape Cod in the NW Atlantic, estimated a similar parameter to I_m , denoting

the flow in the number of squid into the fishing area over a certain period.

Overall then, the dynamics of the biomass on the spawning grounds (B) are described in this study in terms of a composite parameter (g) defined above, a second parameter (I) which reflects immigration to these grounds, and the catches taken (C). At the beginning of month m in year y the biomass on the spawning grounds is given by:

$$B_{y,m} = B_{y,m-1} e^{-g/12} + I_m - C_{y,m-1} + \eta_{y,m} \quad (5.2)$$

$$B_{y+1,1} = B_{y,12} e^{-g/12} + I_{12} - C_{y,12} + \eta_{y,12}$$

where the process error term $\eta_{y,m}$ primarily reflects variation about the expected level of immigration indicated by Equation (5.1), both within and outside the "May-December" spawning season. It also subsumes the effect of monthly variability of g about its average value used in the model, and therefore $\eta_{y,m}$ is assumed to be constant for all months. The monthly catch per unit effort $(C/E)_{y,m}$ is assumed to be proportional to the biomass on the spawning grounds:

$$(C/E)_{y,m} = q B_{y,m} \quad (5.3)$$

where the constant of proportionality q is termed the catchability. Note that this equation omits an observation error term. This is because the analyses that follow rest on the assumption that the variability in the magnitude of the monthly chokka immigration swamps variability in the CPUE-biomass relationship (i.e. process error dominates observation error), so that observation error can be ignored. This assumption is considered to be justified because squid are short-lived and hence recruitment (immigration) is a large component of the biomass on the spawning grounds (Pierce and Guerra 1994). Unlike the situation for longer-lived fish populations which include many cohorts, the resultant variability contributed to Equation (5.2) would be expected to be relatively large in the case of squid.

Combining Equations (5.2) and (5.3) yields:

$$(\hat{C/E})_{y,m} = (C/E)_{y,m-1} e^{-g/12} + qI_m - qC_{y,m-1} \quad (5.4)$$

$$(C/E)_{y,m} = (\hat{C/E})_{y,m} + \eta'_{y,m} ,$$

where $(\hat{C/E})_{y,m}$ is the monthly catch per unit effort predicted by the model, and

$$\eta'_{y,m} = q \eta_{y,m}$$

A process error estimator can then be constructed to estimate the three model parameters (g , I and q) by fitting to the monthly *CPUE* data using a least squares criterion:

$$SS(g, I, q) = \sum \{ \eta'_{y,m} \}^2$$

$$SS(g, I, q) = \sum_{y=1}^n \sum_{m=1}^{12} \left[(C/E)_{y,m} - (C/E)_{y,m-1} e^{-g/12} - qI_m + qC_{y,m-1} \right]^2 \quad (5.5)$$

However, experimentation on this basis showed that the data were not sufficiently informative to admit estimation of all three parameters. Accordingly the value for g was fixed externally, with results being evaluated for three different possibilities ($g = 1, 1.5$ and 2). Values less than 1 were not considered plausible given the short life of this species; values above 2 led to unrealistically high values for the biomass estimated. Taking partial derivatives of SS with respect the composite parameter $I^* = Iq$ and to q , and setting the results to zero, yields a pair of simultaneous linear equations in q and I^* (5.6 and 5.7) which are readily solved to provide estimates for q and I for a given input value of g .

$$\frac{\partial SS}{\partial I^*} = \sum_{y=1}^n \sum_{m=5}^{12} \left[(C/E)_{y,m} - (C/E)_{y,m-1} e^{-g/12} \right] - \left(\sum_{y=1}^n \sum_{m=5}^{12} 1 \right) I^* + \left(\sum_{y=1}^n \sum_{m=5}^{12} C_{y,m-1} \right) q = 0 \quad (5.6)$$

$$\frac{\partial SS}{\partial q} = \sum_{y=1}^n \sum_{m=5}^{12} C_{y,m-1} \left[(C/E)_{y,m} - (C/E)_{y,m-1} e^{-g/12} \right] - \left(\sum_{y=1}^n \sum_{m=5}^{12} (C_{y,m-1}) \right) I^* + \left(\sum_{y=1}^n \sum_{m=5}^{12} (C_{y,m-1})^2 \right) q = 0$$

(5.7)

where m corresponds to the months when I is non-zero.

Note that this process corresponds to maximum likelihood estimation if the assumption is made that the η' are normally distributed. Other forms could be argued for this distribution, but they would not have the convenience of closed form solution for q and I^* , as does the normality assumption.

The process error variance ($\hat{\sigma}^2$) was estimated from

$$\hat{\sigma}^2 = \frac{1}{n} \sum (\eta'_{y,m})^2, \quad (5.8)$$

where n is the number of year-month combinations considered. Values for $CPUE$ can be unrepresentative in months with low fishing effort, which likely correspond to large sampling variability. The summation in Equation (5.8) therefore excluded all months for which the effort level was less than 5 000 h, which corresponds approximately to 2% of the effort deployed by the current fleet. The months excluded as a result of applying this criteria were: January - July 1985, and November of 1989 and 1990. This is in the spirit of the process error estimator approach used here, which assumes that observation error is zero. These exclusions effectively omit data for which the observation error might be high.

Sensitivity tests were undertaken on the assumption of a constant g throughout the year and on the value of the threshold in the stock-recruit relationship. The details and results of these tests are presented under the section Results and Discussion.

5.2.3 Bootstrap estimation of confidence intervals

Simulated time-series of $CPUE$ $[(C/E)^s_{y,m}]$ were generated by parametric bootstrapping for the three values of \hat{g} considered, given the associated best estimates of the model parameters: \hat{I} , \hat{q} and \hat{g} . Each such new data set was generated by randomly sampling from the normal probability distribution estimated for the residuals and adding a "new" residual to each predicted data point:

$$(C/E)_{y,m}^s = (C/E)_{y,m-1}^s e^{-\hat{g}/12} + \hat{q} \hat{I}_m - \hat{q} C_{y,m-1}^s + \eta_{y,m}^{*s}, \quad (5.9)$$

where η^* is drawn from a normal distribution $N(0, \sigma^2)$ and the first *CPUE* value in the series was taken to be equal to that observed. Note that each $(C/E)_{y,m-1}^s$ is treated as the preceding “actual” data point when the $(C/E)_{y,m}^s$ value is generated. While such bootstrap re-sampling is generally straightforward for observation error estimators, some care has to be taken in a process error situation to preclude unrealistic outputs. Therefore, in order to reduce the possibility that Equation (5.9) generates negative *CPUE* values, the simulations were conditioned on the observed effort values, so that the simulated catches used in that equation were

$$C_{y,m-1}^s = (C/E)_{y,m-1}^s E_{y,m-1}. \quad (5.10)$$

Nevertheless, some negative *CPUE* values arose. To overcome this problem, the error term η^* was regenerated whenever the *CPUE* that would otherwise have followed under Equation (5.9) was less than 5% of the previous month’s value. In spite of this constraint, a small number (less than 10% of the simulated time-series), resulted in negative parameter estimates that are not biologically realistic. This proportion was considered sufficiently small for them to be discarded, with inferences concerning precision being based on the remainder.

This process was used to provide 1 000 replicate sets of parameter estimates which, on ordering, provided estimates of confidence intervals directly.

5.2.4 Projections

After obtaining estimates of the parameters \hat{I} , \hat{q} and $\hat{\sigma}$ and their confidence limits, these estimates were used to assess the impact of various levels of effort and of the closed season on the resource and fishery. Time-series of *CPUE* were generated by projecting the biomass forward using the most recent observation $(C/E)_{1996,12}$ as a starting point, and a set of parameters estimated from one of the bootstrap replicates (\hat{I}^s , \hat{q}^s and $\hat{\sigma}^s$). These projections covered a period of 10 years, during which the annual fishing effort

level was kept constant, and followed the average monthly pattern observed in the fishery since 1988, when the closed season was first enforced (Fig. 5.1).

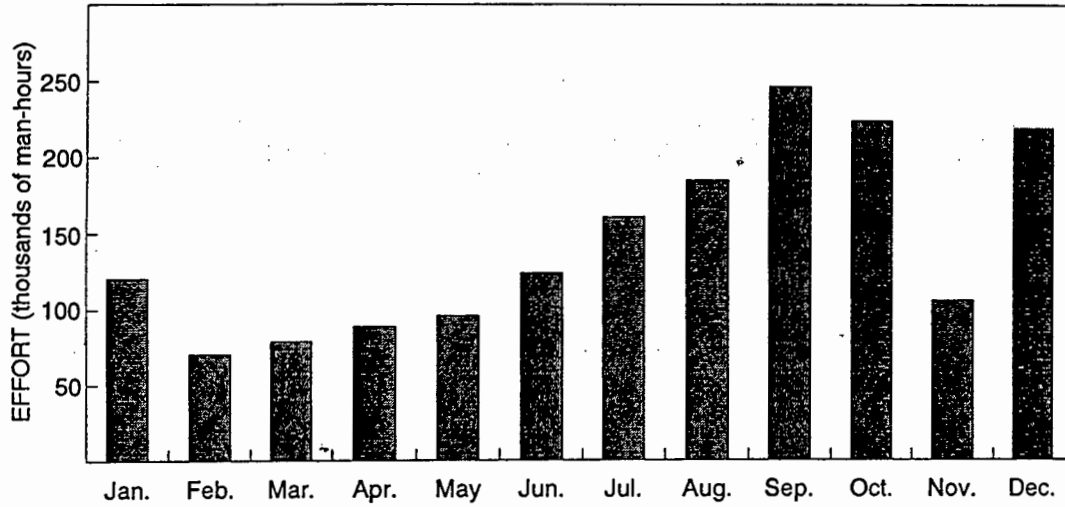


Fig. 5.1: Average monthly effort in the South African chokka jig fishery estimated from data from 1988 to 1995

Thus, the simulated *CPUE* for a future year and month was given by:

$$(C/E)_{y,m}^s = (C/E)_{y,m-1}^s e^{-g/12} + q^s F_m - q^s C_{y,m-1}^s + \eta_{y,m}^{*s} \quad (5.11)$$

where $\eta_{y,m}^{*s}$ was drawn from $N(0, (\sigma^s)^2)$.

The simulated catch $C_{y,m}^s$ was set by

$$C_{y,m}^s = \min \{ (C/E)_{y,m}^s E_m; 0.95 B_{y,m}^s \} \quad (5.12)$$

where $B_{y,m}^s = (C/E)_{y,m}^s / q^s$ and the effort E_m applied in a particular month is given by

$$E_m = E_{\max} \lambda_m \quad (5.13)$$

where E_{\max} is the maximum monthly effort applied in a year (in September, so that $\lambda_{\text{September}} = 1$ - see Fig. 5.1).

In the projections, E_{\max} was increased in steps to a level where the resource was considered seriously depleted, in order to investigate the effects of different levels of

effort, with and without the closed season. The closed season scenario was simulated by applying the past average monthly effort pattern, whereas that without a closed season had the maximum effort from September to November, i.e. $\lambda_m = 1$ for those three months. The "risk" associated with a particular effort level E_{\max} was defined as the proportion of the 1 000 projections in which the average biomass between October and December fell below 20% of the average pristine, defined as completely unfished, spawning biomass for the parameters of that simulation, at least once within 10 years. The period October - December was chosen as representative of the effective spawning biomass based on the morphological studies of Augustyn (1989) and Sauer (1991), coupled with behavioural observations (Sauer *et al.* 1992) that indicate that the spawning intensity is at its maximum during those months.

In the absence of any information on the relationship between the size of the parental stock and subsequent immigration, the average immigration level, I , was assumed to be constant, as in Equation (5.1), provided the average biomass between October and December of the previous year was >20% of the average pristine biomass for the same three months. Below this threshold, I and the standard deviation of the associated process error, η^* , were reduced linearly in proportion to the spawning biomass in the previous year, as shown in Figure 5.2. This 20% threshold level was suggested in a paper by Clark *et al.* (1985) and has been used frequently since in fishery management evaluations (e.g. Butterworth *et al.* 1993 for the South African anchovy) as indicative of a level below which spawning success might be impaired. Basson and Beddington (1993) refer to a threshold level of 14% for the Falkland Islands *Illex argentinus* fishery, which they advance on the basis of the lowest estimated spawning biomass level that had led to viable recruitment in the following year. However, in light of the weak basis for their suggestion, they also investigated the sensitivity of their results to this assumption by considering two other levels, 7 and 27%. The standard choice of 20% was retained here, noting that it reflects a more conservative approach than would use of the 14% suggested by Basson and Beddington (1993).

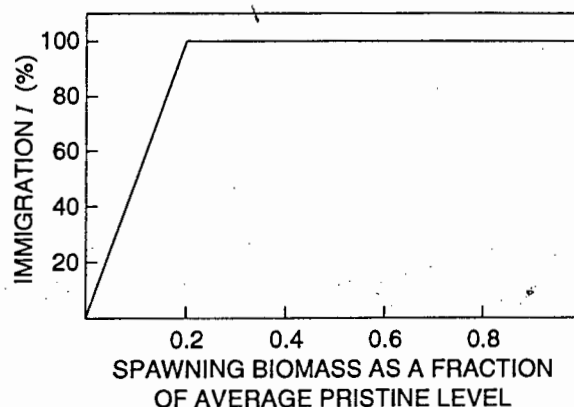


Fig. 5.2: Monthly immigration (I) in relation to previous year's spawning biomass of chokka squid

5.3 RESULTS AND DISCUSSION

The parameter estimates, with their corresponding 95% confidence intervals represented by the 2.5th and 97.5th bootstrap percentiles, are given in Table 5.I. The near invariance of the estimates of σ as g is varied reflects the earlier assertion above that there is insufficient information in the *CPUE* data to estimate all three of the q , I and g parameters. The consequence of increasing g is an increase in the estimate of immigration I to compensate for the higher net losses, and a decrease in q . In fact the three parameters q , I and g are correlated. This is the case when the *CPUE* time-series provides little contrast. A *CPUE* time-series as the one used in this study, is called the one-way-trip by Hilborn and Walters (1992) because it reflects a history of a fishery with continuous increase in fishing effort and decline in *CPUE*. It is seen as very difficult to interpret.

Table 5.I: Estimates of model parameters I (immigration), q (catchability) and σ (standard deviation of the residuals), together with 95% confidence intervals (CI), for three values of the composite parameter g

g	q	CI	I (tons)	CI	σ	CI
1.0	0.465E ⁻⁶	0.14E ⁻⁶ ; 1.10E ⁻⁶	1 479	825; 3 940	0.114E ⁻²	0.096E ⁻² ; 0.124E ⁻²
1.5	0.377E ⁻⁶	0.091E ⁻⁶ ; 1.06E ⁻⁶	1 984	988; 7 400	0.1134E ⁻²	0.094E ⁻² ; 0.122E ⁻²

g	q	CI	I (tons)	CI	σ	CI
2.0	$0.293E^{-6}$	$0.051E^{-6}$; $976E^{-6}$	2 752	1 108; 13 647	$0.113E^{-2}$	$0.094E^{-2}$; $0.122E^{-2}$
1.0*	$0.556E^{-6}$	$0.69E^{-6}$; $1.23E^{-6}$	1 121	1 108; 2 381	$0.116E^{-2}$	$0.11E^{-2}$; $0.124E^{-2}$

* g variable over the year (see text)

Table 5.II: Performance statistics estimated in the 10-year projections, under different model scenarios

Scenario		Performance criteria			
g	Threshold	Maximum yield (tons)	Corresponding annual effort (million man-hours)	"Risk" * at current level of effort (%)	Depletion† at current level of effort (%)
1.0 (base case)	0.2	7 708	5.15	76	30
1.5	0.2	10 029	8.71	51	43
2.0	0.2	13 597	13.45	35	52
0.5 ; 2.5‡	0.2	6 646	4.18	79	24
1.0	0.5	3 696	1.53	99	1

• "Risk" is the probability that the spawning biomass falls below 20% of its average pristine level at least once during the 10-year projected period

† Depletion is the average spawning biomass at the end of the projection period expressed as a proportion of its average pristine level (i.e. average in the absence of fishing)

‡ g variable throughout the year

The confidence intervals of the parameters are wide and indicate skew distributions. For the moment, effort is concentrated on the *base case* with $g = 1$. As this is the case with the lowest biomass estimates, it is likely to be the one that leads to the greatest concerns in any "risk" context.

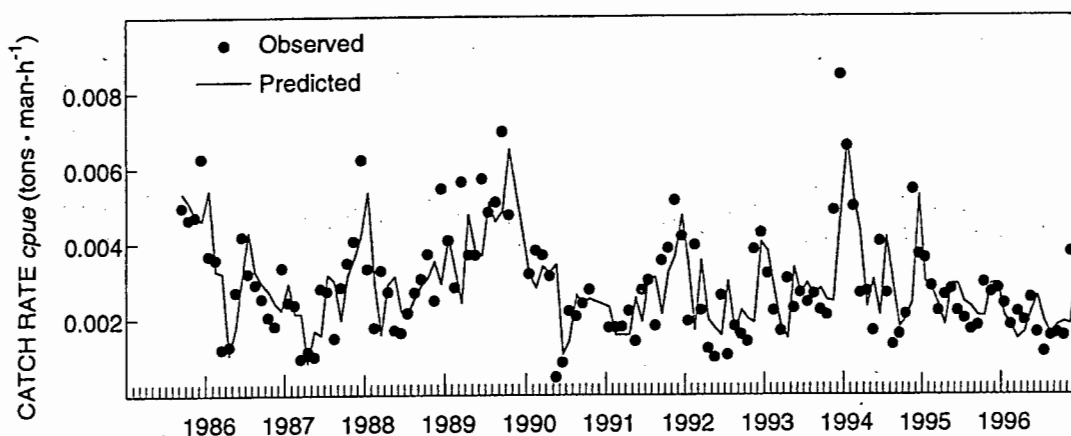


Fig. 5.3: Observed and model-predicted monthly catch rate according to the base case

The observed and model-predicted *CPUE* values for $g = 1.0$ are shown in Figure 5.3. The apparently good agreement is misleading in that it is to a large extent a consequence of the process error estimator approach which uses the observed *CPUE* from one month to predict the *CPUE* for the following month - see Equation (5.4). In fact, once this factor is discounted, the predictive ability of Equation (5.4) is seen to be quite weak - a reflection of the rather large value of the residual standard deviation, σ (see Table 5.I), which in turn suggests that immigration varies considerably from month to month. A plot of the residuals from the model by month and year, is presented in Figure 5.4. The residuals do show some trends, particularly in January and May, which suggests the need to test sensitivity to the choice of months during which immigration is assumed to take place. The positive residuals in November could be related to circumstances of the closed season, when fewer boats operated for part of the month. Nevertheless, the model has allowed a first estimation of key parameters such as immigration to the spawning grounds (I), and of the underlying dynamics of the resource.

The associated estimated biomass time-series is shown in Figure 5.5 together with the actual catches. Although, of the three values considered, $g = 1$ leads to the lowest estimated biomass levels, these still remain well above the actual catch at all times.

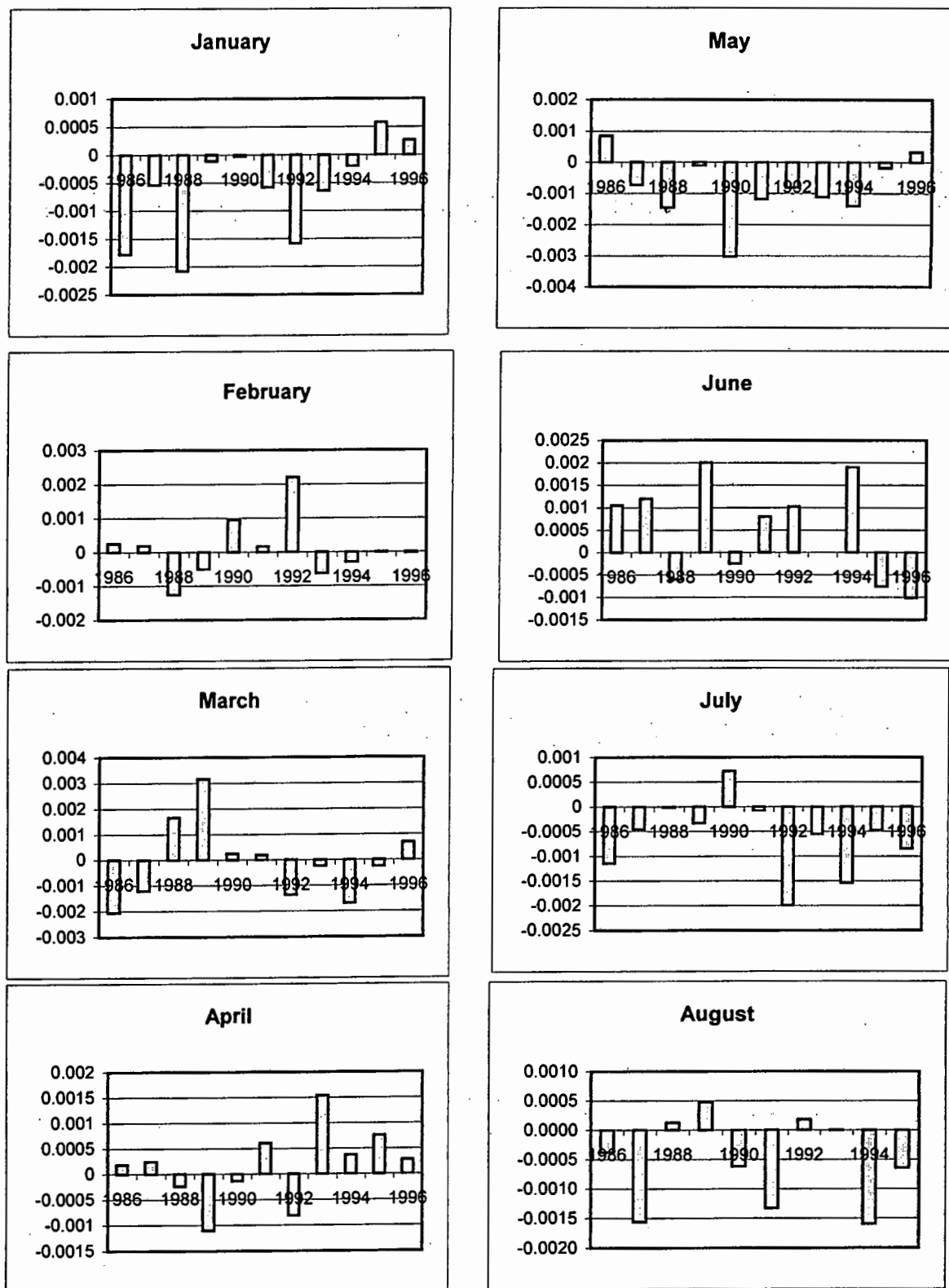


Fig. 5.4: Plot of the residuals from the model, by month.

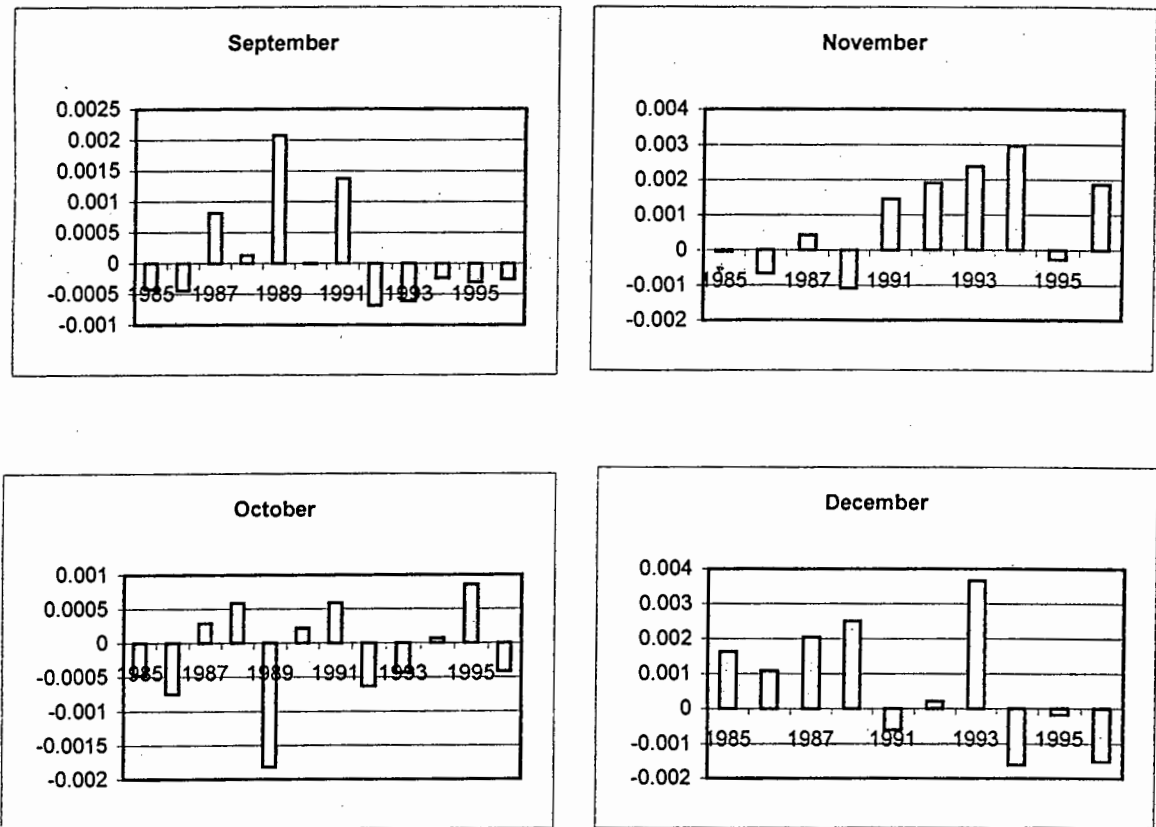


Fig. 5.4: Plot of the residuals from the model, by month.

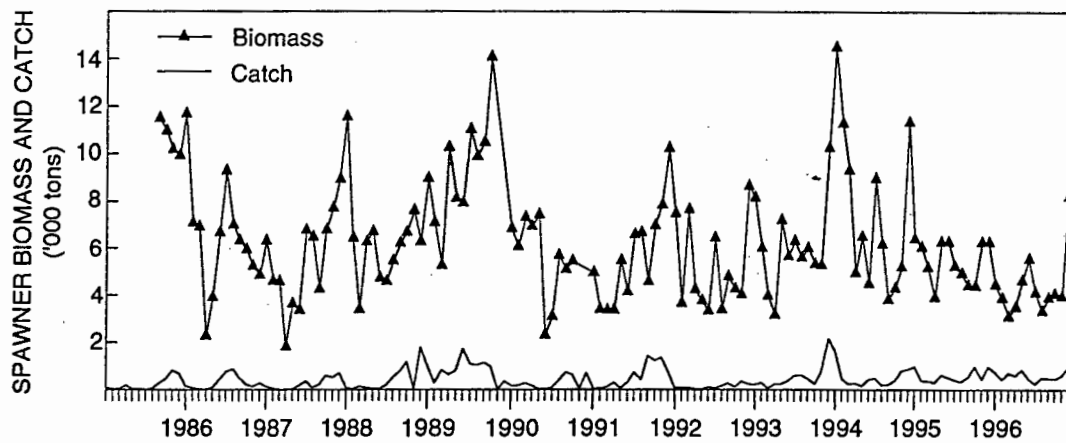


Fig. 5.5: Base case scenario estimates of spawning biomass and actual monthly catch data in the chokka squid jig fishery

5.3.1 Evaluation of the effects of different effort levels and of the closed season

The effects of different levels of fishing effort, both with and without a closed season, on the resource biomass and the expected catches are shown in Figures 5.6 and 5.7. In both cases the effort shown on the horizontal axis corresponds to that in September, i.e. the month for which the effort is at its maximum over the year ($\lambda = 1$, see Equation 5.13).

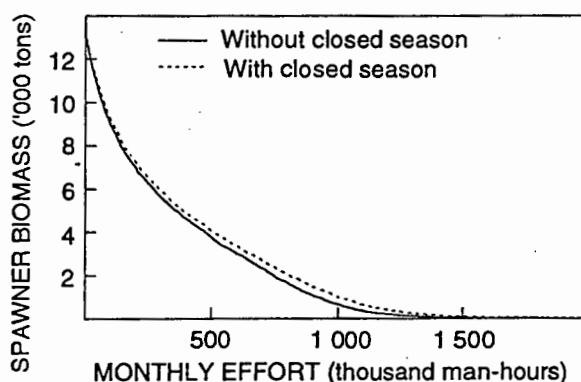


Fig. 5.6: Average spawning biomass of chokka squid at the end on 10-year projections with and without a closed season in place, according to the base case

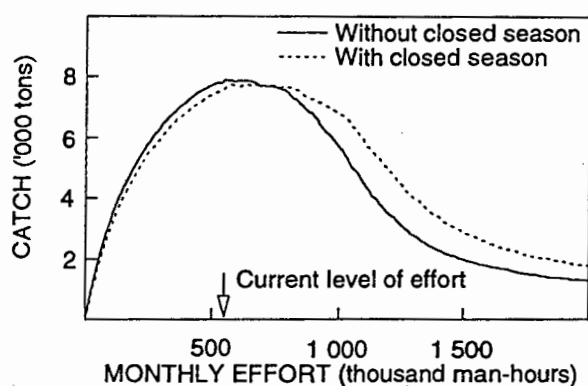


Fig. 5.7: Median annual catch of chokka squid over 10-year projections with and without a closed season in place, according to the base case

The effective spawning biomass, calculated as the average of this biomass at the start of each of October, November and December, at the end of the 10-year projection

period is represented in Figure 5.6 by the median over 1 000 simulations. This plot shows that the biomass is only marginally higher for the same maximum monthly effort when the closed season is in place. However, Figure 5.7 does indicate some gain in median annual catch given a closed season when the maximum monthly effort level is more than a million hours. Nevertheless, the improvement derived from the closed season is slight, which is not surprising given that it achieves only a 9% reduction of total annual effort. In reality, if the closed season results in a shift of some of the effort that would otherwise have been applied at that time to the rest of the fishing season, the conservation benefit would be even less.

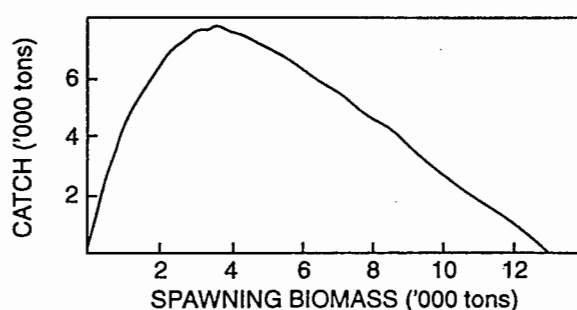


Fig. 5.8: Relationship between catch and spawning biomass of chokka squid over 10-year projections

The other primary question to be addressed is the appropriateness or otherwise of the current effort level in the light of these computations. An estimate of the annual effort currently exerted on the resource is 3.6 million hours, which corresponds to an effort level of 520 thousand hours in terms of a monthly maximum. Figure 5.6 shows that the spawning biomass would have been reduced to about one-third of its average pristine level under that level of fishing. Whether or not this indicates that the resource is being overexploited depends on the level of spawning biomass at which the maximum yield from the resource is attained. In order to determine that level, the median catch at the end of a 10-year projection at a constant level of effort was plotted against the corresponding spawning biomass at the end of that same period. The process was repeated at various levels of increased effort to generate the catch v. spawning biomass curve shown in Figure 5.8. The results indicate that, on average, the maximum sustainable yield is at biomass levels in the vicinity of 25% of pristine. The maximum yield that could be

obtained from the resource as estimated in these simulations, and the annual effort that generates it, are shown in Table 5.II for the various scenarios investigated. For the base case, current effort is well below the level generating maximum yield.

However, in addition to examining maximum average catch, in order to properly evaluate the long-term impact of such a level of effort, other performance statistics need to be examined. For example, the associated risk of falling below 20% of the average pristine spawning biomass level ("20% pristine") is estimated to be as high as 76%, a level much higher than the 30% over a 20-year period applied at present in managing the South African anchovy resource (Butterworth *et al.* 1993), also a short-lived species. The lowest spawning biomass levels attained are represented by the lower 5 percentiles of the distribution of lowest biomass values obtained in the 10-year projections. They are plotted in Figure 5.9. The graph shows that the 20% pristine level corresponds to relatively low levels of effort, again indicating very little benefit obtained from the current closed season.

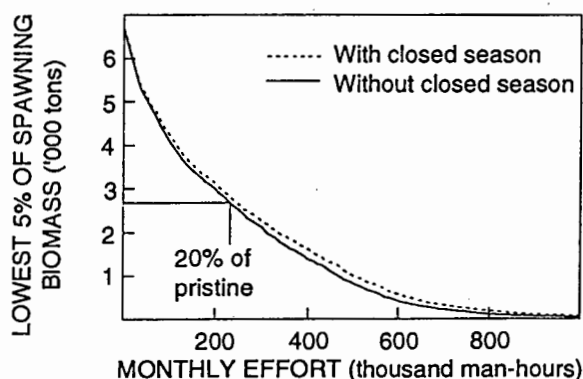


Fig. 5.9: Lowest 5% of spawning biomass distribution of chokka squid over 10-year projections with and without a closed season in place.

In summary, there is no major biological or economic benefit to be derived from the existing closed season if the maximum monthly effort remains below 700 000 hours. Conversely, at effort levels greater than 800 000 hours, catches are better under a closed season (see Fig. 5.7) because, in such circumstances, the long-term biomass level of the stock is improved. At present, with effort levels of about 520 000 hours (monthly maximum), these considerations alone suggest a case for allowing the effort to increase

further. In addition, results from the projections indicate that there is a 72% probability that the current level of effort is below that corresponding to maximum catch. However, as shown by the wide distributions associated with the median catch v. effort plot in Figure 5.10, this statistic is poorly determined by the catch and effort data used for the present analysis.

Sensitivity to some of the most important model assumptions were tested. The base case assumes constant g , and this assumption could be challenged by observations which indicate that the chokka “disappears” from the fishing grounds in the first months of the year. To mimic this perception, calculations were repeated under a variable g pattern consisting of two levels of g : a low value prevailing during most of the year, including the spawning season, and a high value at the beginning of the year:

$g_{\text{low}} = g * 0.5$, from April to December ,

$g_{\text{high}} = g * 2.5$, from January to March .

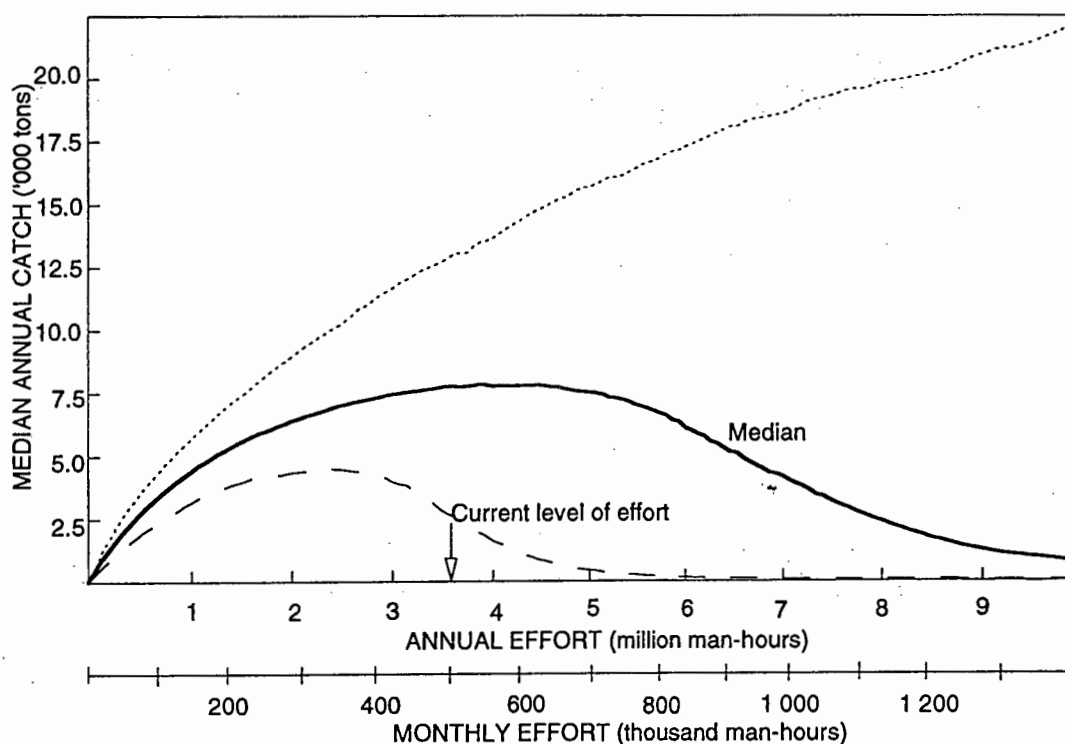


Fig. 5.10: Median annual catch of chokka squid over 10-year projections, and the corresponding 95% probability intervals at different levels of effort.

The values of 0.5 and 2.5 are such that the cumulative g over the year would be the same as in the base case to ensure comparability of the results. The resulting

parameter estimates and confidence intervals are included in Table 5.I. The results regarding any benefit to be derived from the existing closed season are similar to those for the base case. However, the resource seems to be less productive under these conditions: note the lesser maximum yield in Table 5.II.

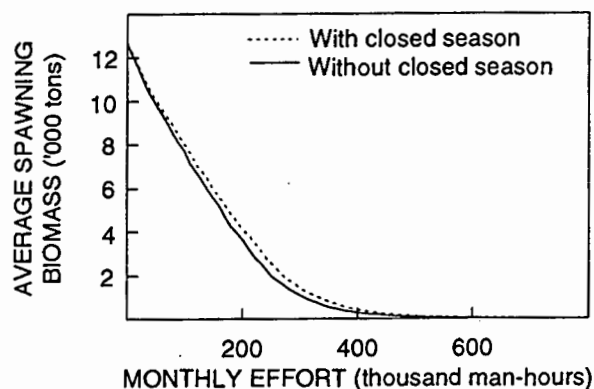


Fig. 5.11: Average spawning biomass of chokka squid at the end of 10-year projections with and without a closed season in place (stock-recruit threshold = 0.5 – see text)

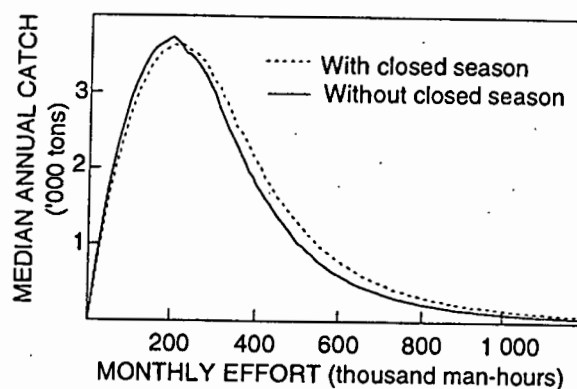


Fig. 5.12: Median annual catch of chokka squid over 10-year projections with and without a closed season in place (stock-recruit threshold = 0.5 – see text)

Sensitivity to the threshold value of 0.2 used for the stock-recruit relationship (see Fig. 5.2) was also explored. The average annual catches over 10-year projections and the biomasses at the end of the 10 years are presented in Figures 5.11 and 5.12. The obvious effect of raising this threshold level is a decrease in the productivity of the resource. The spawning biomass declines very rapidly with effort level, as shown in Figure 5.11 (compared to the equivalent plot for the base case in Fig. 5.6), and the maximum annual catch is reduced to just less than 4 000 tons (Table 5.II), less than half of that for the base case. Therefore, the actual level of this threshold is crucial when it comes to inferences of whether or not the current effort level is less than would provide a maximum yield. Note, however, that these computations for the high threshold are likely to be negatively biased; they depend on parameters estimated from Equation (5.5), which ignores that

threshold. This does not matter for calculation with a threshold of 0.2 because the spawning biomass is estimated not to drop below this level during the period 1988-1996 considered for the estimation, but this argument would not apply if the threshold level was 0.5.

5.4 CONCLUSIONS

This analysis has highlighted several important gaps in knowledge and data availability which have prevented a more comprehensive assessment of the status and dynamics of the stock under consideration. In particular, the following areas need further investigation in order to improve the reliability of the assessment.

- The relationship between *CPUE* and spawning biomass should be investigated, especially considering the recent expansion of jigging operations into water deeper than the traditional fishing grounds. This is particularly important in view of the current dependence on *CPUE* as an index of abundance. However, describing the relationship will not be easy, because there are currently no reliable fisheries-independent estimates of biomass. A comprehensive analysis of trends in *CPUE* using, for example, generalized linear modelling, could improve interpretation of these data and comparison with other fisheries indices, e.g. the demersal fishery, which takes squid as a bycatch (Cochrane *et al.* 1997). In addition, fisheries-independent surveys have been undertaken on the Agulhas Bank since the early 1980s. These do not cover the full area occupied by squid during the spawning season, because the ships utilized are too big to survey the shallow water where most spawning takes place. However, if a relationship between the survey estimates and the true stock biomass was found to be sufficiently precise, this index could be included in the model as an additional abundance measure.
- Biological research into determination of chokka squid lifespan would permit constraining the possible values of M (and hence g) and could also allow the development of an age-structured model if adequate data to estimate length composition of the catches became available.
- Research to determine more precisely the area where spawning takes place could result in an improved stock-recruit relationship or, at least, define better what

constitutes the spawning stock.

- Similarly, an investigation into the sensitivity of the results to the choice of months used to estimate mean spawning biomass and to the ones in which immigration takes place, coupled with improved knowledge of monthly spawning activity, could improve the precision of the model.

Notwithstanding the above reservations, the calculations in this Chapter indicate that the biological and economic gains provided by the current closed season are small, consistent with the approximately 9% reduction in effort which they represent. While the benefits may be greater at higher effort levels than those currently being applied, such levels correspond to high risks of depleting the spawning biomass to levels at which the chance of successful recruitment might be impaired, and are therefore not feasible management options, even with a closed season. However, decisions on the desirability or otherwise of maintaining the closed season should not be taken without consideration of the effort level in the fishery as a whole.

Providing advice at this stage on an appropriate level of effort for the fishery is difficult for two reasons:

- (i) Although point estimates indicate that the current level of effort is below that which would lead to a maximum yield, these estimates are not very precisely determined (Fig. 5.10) and therefore need to be interpreted with caution.
- (ii) Risk-related statistics (indicating that risk is already very high at the current level of effort under the base-case assumptions of these analyses) are very sensitive to the assumptions made in the model, in particular to the assumed value and pattern of the composite parameter g and to specification of the spawning biomass level below which average recruitment is likely to fall. Further, there is both little information from squid fisheries elsewhere in the world upon which to base an informed opinion on this matter, and little prospect of immediate resolution on these points for this particular fishery.

Although, therefore, the closed season seems little more than a mechanism for effort reduction on the basis of the results above, it would seem prudent in view of the

apparently high levels of risk associated with the current effort level, to maintain it and certainly not to allow it to increase until greater clarity on the matters raised in points (i) and (ii) above becomes available. This is consistent with the precautionary approach advocated as essential for responsible fisheries management. Above all, the precautionary approach calls for prudent foresight and priority to be given to conservation of the resource under circumstances where the impact of fisheries on the resource is uncertain (F.A.O. 1996), as is being recommended here. South Africa's recent White Paper on Marine Fisheries (Anon. 1997) also advocates application of the precautionary approach in such cases.

The risk levels estimated in this study suggest that some consideration needs to be given to reducing the current level of effort. However, in view of the existing sensitivities regarding access to the resource and the fact that reducing the number of participants in the fishery would be very difficult under existing socio-political circumstances, it is probably preferable to achieve the required reduction in effort by increasing the length of the existing closed season rather than by attempting to reduce the numbers currently having access to the fishery.

CHAPTER 6

Application of a biomass-based model to fit time-series of biomass indices

6.1 INTRODUCTION

Biomass-based models are the simplest models used in fisheries stock assessment. They are often referred to as production models or as surplus production models. In such models, the size/age structure of the stock is ignored and the model only deals with stock biomass. Following Hilborn and Walters (1992), if we ignore immigration and emigration the changes in a population's biomass from one year to the next can be written as

$$\text{Next biomass} = \text{last biomass} + \text{recruitment} + \text{growth} - \text{catch} - \text{natural mortality}.$$

In the absence of fishing, surplus production is the difference between the processes that result in biomass gain, and the effects of natural mortality. Simple models, referred to as biomass-based models and ignoring age structure, can be written as:

$$\text{New biomass} = \text{old biomass} + \text{surplus production} - \text{catch}.$$

There are various reasons for choosing biomass-based models to assess a fish stock. The two more important ones are: 1) paucity of data, so that age/size composition data are either not reliable or non-existent; 2) they often produce more precise estimates of the quantities of interest for management than do more complex approaches that give a better representation of the underlying biological reality (Ludwig and Walters 1989).

The methods used to estimate biomass model parameters are very important as regards their implications for the accuracy and precision of the estimates obtained (Polacheck *et al.* 1993). Those authors refer to four approaches used to fitting such models:

1. Equilibrium methods, based on the assumption that the stock is at equilibrium. However, exploited stocks are rarely at equilibrium, and hence the recommendation "never use equilibrium methods" stressed by Hilborn and Walters (1992). Biomass models that do not make the continuous equilibrium assumption are known as biomass dynamic models (Butterworth 1988).
2. Effort-averaging approaches. These are the simplest way of overcoming the problem of non-equilibrium. Strictly the approach assumes that recruitment is independent of stock size, and violation of this assumption is more likely to be a problem in the case of short-lived species such as chokka. Further, Polacheck and his co-authors found this estimator to be positively biased when applying it to four fish stocks.
3. Process-error methods make use of process-error estimators, which are based on the assumption that observations are made without error and that all the error is in the equation that represents the changes in biomass. "Process error" occurs because of variability in recruitment and natural mortality, and because age- and size-structure effects are ignored in the formulation of the dynamics (Punt and Hilborn 1996). A process-error estimator approach to assess the status of the chokka resource was taken in Chapter 5 of this study because the variability in monthly biomass is quite possibly much greater than the measurement error. It is not possible to take account of more than one time-series of abundance indices for a process-error estimator because of the premise that the observations are made without error.
4. An observation-error estimator is constructed by assuming that the population model is deterministic and that all error is included in the relationship between the observed index of abundance and the biomass. Possible sources of observation error are sampling error (e.g. Kirkwood 1981) and fluctuations in catchability.

Fisheries stock assessment results are used primarily as input for some form of decision-making process and, as this process becomes more quantitative, the demands on stock assessment are changing, putting greater emphasis on incorporation of uncertainty (McAllister *et al.* 1992, Francis and Shotton 1997). A key element of fisheries stock assessment is the uncertainty associated with current stock size and productivity. This uncertainty leads to risk when making management decisions. In

this study only biological risk, defined as the probability of falling below 20% of the average pristine level over a 10-year simulation period, is considered. Risk levels associated with different levels of fishing effort are estimated. However, this raises the question of what is an acceptable level of risk (in terms of this definition) for this resource, and this needs to be addressed at the time of making management decisions.

In this Chapter, an assessment of the chokka stock is conducted in order to assess its status (e.g. in terms of productivity and trends in stock size) and to provide some of the scientific information pertinent to the formulation of management decisions. In order to do so:

- a biomass dynamic model that uses an observation-error estimator was developed. The main reasons for having opted for this approach are:
 - it has the ability to take account of more than one CPUE series,
 - in the approach taken in Chapter 5 the time step was a month, with high CPUE variability related to high inter-month recruitment variation (hence large process error). In this Chapter the time step is either 3 or 9 months so that the size of the net process error is much smaller,
 - there is merit in capturing the results under different estimation methods to check sensitivity,
 - simulation studies (Polacheck *et al.* 1993), indicate that observation-error estimates give robust results even in the presence of not inconsiderable process error.
- for the purpose of estimating basic population parameters, the model was initially developed to fit six abundance indices:
 - two jig CPUE indices, one obtained from January - March data and the other from April - December data,
 - two trawl abundance indices, corresponding to January - March, and April - December,
 - an autumn survey index, which corresponds to estimates of stock biomass obtained by those scientific surveys, and
 - a spring survey index, the estimates of stock biomass from spring scientific

surveys;

- the year was divided into two periods, January - March and April - December, to simulate better the dynamics of the resource and of the two fisheries, particularly as relates to the times at which recruits entering the fishery (see Chapter 3), the model for the changes in biomass is therefore biennial.

6.2 MATERIAL AND METHODS

6.2.1 Data

The catch data consist of annual information from 1971 to date and include all catches from the commercial fishery. Both sets of data, jig and trawl, are split into catches taken in the first three months and those taken in the remaining part of the year.

Two abundance indices from the trawl fishery are used: one corresponding to the first three months of the year and the second corresponding to the months April to December. Both indices were standardized by means of GLM, as described in Chapter 4. This was done by separate analyses (not reported in detail in Chapter 4), using only the data from a given period. Data to perform the GLM analysis were available from 1978 to 1996. These abundance indices show a very sharp decline between 1980 and 1984 that could not be modelled by means of the approach taken here. Therefore, only the values of these abundance indices from 1984 to 1996 are used as the base case in this Chapter. A further refinement of this modelling approach that is able to reflect the decline prior to 1984 is developed in Chapter 7.

The annual jig CPUE index was computed in the same manner as described in Chapter 5, and is expressed in kilogrammes caught per man on board per hour fishing. Two series were computed, one for January - March, and the other for April - December. Jig fishing effort has increased substantially early in each year since the early 1990s, a feature related to the introduction of freezer boats to the fishery and an increase of operations offshore of the spawning grounds (see Chapter 3). Distance from shore, or water depth data is not available for the jig catches and therefore it was

not possible to standardize the jig CPUE by means of a GLM. This major change in fishing pattern affects primarily the first months of the year, having a negative impact on the overall consistency of the time-series derived from catch and effort data for this period and undermining its value as an index of abundance. Therefore, the January – March CPUE index for the jig fishery was excluded from the base case (though sensitivity to this index's exclusion is also investigated below).

The survey data correspond to the swept area biomass estimates from the South Coast demersal trawl surveys undertaken every autumn (April/May) and spring (September) since 1986. Although a coefficient of variation is available for each of the survey estimates, it has not been used as a weighting factor in this analysis. The reason is that these CVs are based on sampling variability only, and thus underestimate (by perhaps quite a large extent) the overall variance associated with these estimates. The estimator developed assumes that these overall CVs are the same for all the surveys. A full description of the properties of the commercial fishery and of the scientific data, as well as of the methodology used to derive each of the time-series, is provided in Chapter 4 of this study. For a summary of the main features of the time-series of data used, see Tables 1.I and 4.I.

6.2.2 The Model

The resource dynamics were modelled by a very simple biomass equation. Deterministically, the general form of the model is the following:

$$B_{y+1} = B_y e^{-g} + R_y - C_y \quad (6.1)$$

where R_y is the recruitment in year y , which the model assumes to occur as a pulse at the start of April,

g is a composite parameter which accounts for natural mortality, emigration and growth (see Chapter 5 for rationale); $g = 0$ in the case of R_y ,

C_y is the catch in year y .

The biomass gains are represented by the recruitment term (R_y) which is equal to:

$$R_y = \begin{cases} R; B_y \geq 0.2K \\ \lambda B_y; B_y < 0.2K \end{cases} \quad (6.2)$$

where B_y is the biomass at the beginning of year y ,

$\lambda = R / (0.2K)$, and

K is the pristine equilibrium biomass (see Equation 6.26 following).

As discussed in Chapter 5, recruitment occurs preferentially during the May-December period. This is modelled by an aggregate parameter R that nominally appears in the equations as a pulse at the start of April, but in effect it is a measure of recruitment integrated over the April-December period, making allowance for the effects of growth, mortality and emigration during that period.

It is assumed that the catch rate is proportional to the average stock size over the $y, y+1$:

$$(C/E)_y = q \frac{B_y + R_y + B_{y+1}}{2} \quad (6.3)$$

E_y is the fishing effort in year y and

q is the catchability.

6.2.3 General properties of the basic model used

For the model developed here, the general form for the total catch C_y in year y can be derived from Equations (6.1) and (6.3) above and equals:

$$C_y = \frac{qE_y}{1 + \frac{1}{2}qE_y} \left[B_y \frac{1 + e^{-g}}{2} + R_y \right] \quad (6.4)$$

Under equilibrium conditions $B_{y+1} = B_y = B$, $R_y = R$ and $C_y = C$. Therefore, substituting in Equation (6.1):

$$B = \frac{R - C}{(1 - e^{-g})} \quad (6.5)$$

Substituting B in (6.4) by the right-hand side of (6.5) and solving for C , the relationship between fishing effort (E) and sustainable yield is found to be given by:

$$C = zR \frac{1 + \alpha}{1 + z\alpha} \quad (6.6)$$

where $z = \frac{qE}{1 + \frac{1}{2}qE}$, and

$$\alpha = \frac{1 + e^{-g}}{2(1 - e^{-g})}$$

For R constant (i.e. irrespective of biomass B), the maximum catch C_{\max} that can be taken occurs as the biomass tends to 0, in which case Equation (6.5) indicates that $C_{\max} = R$. Furthermore equation (6.6) can be rewritten:

$$C = R \frac{(1 + \alpha)qE}{1 + (\frac{1}{2} + \alpha)qE} \quad (6.7)$$

From (6.7) it can be shown that, when $C = C_{\max} = R$, the corresponding effort (E_{\max}) is equal to:

$$E_{\max} = \frac{2}{q} \quad (6.8)$$

This perhaps surprising result of a maximum equilibrium effort is evident by taking (6.5) and (6.7) together, and eliminating C , which yields:

$$B = \frac{R}{1 - e^{-g}} \frac{1 - \frac{1}{2}qE}{1 + (\frac{1}{2} + \alpha)qE} \quad (6.9)$$

for which it follows that, for $qE > 2$, the equilibrium biomass becomes negative,

which is impossible.

In the model considered here, recruitment (R) is taken to depend on the stock biomass (B) when $B < 0.2 K$. In that case $R(B) = \lambda B$, where $\lambda = R/0.2K$. Then from (6.5):

$$C = B[\lambda - (1 - e^{-g})] \quad (6.10)$$

and from (6.3)

$$(C/E)_y = q \left[B_y \frac{1 + e^{-g}}{2} + R_y - C_y/2 \right] \quad (6.11)$$

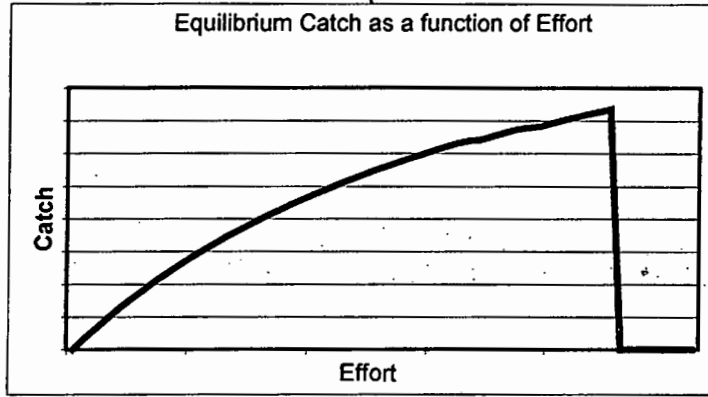
Hence

$$C_y = \frac{qE_y}{1 + qE_y/2} B_y \left[\lambda + \frac{1 + e^{-g}}{2} \right] \quad (6.12)$$

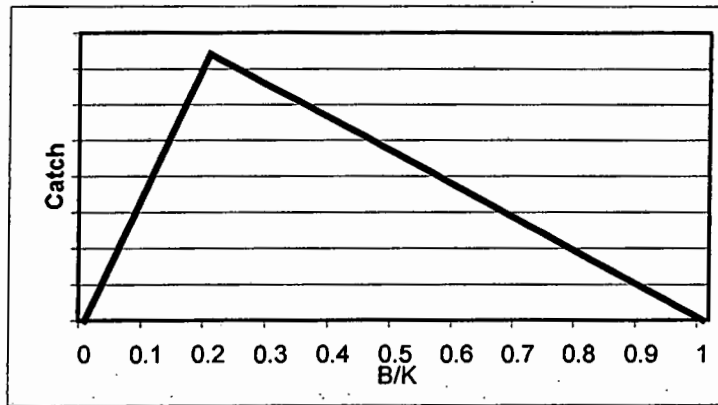
For $B < 0.2 K$, the effort (E_{\max}^*) and the corresponding catch $C = C_{\max}^*$ can be derived by equating the separate expressions provided for C/B by Equations (6.10) and (6.12):

$$E_{\max}^* = \frac{1}{q} \left[\frac{\lambda - (1 - e^{-g})}{1 + \lambda/2} \right] \quad (6.13)$$

For any value of $B < 0.2 K$, the same value of $E = E_{\max}^*$ will keep the biomass at equilibrium. Values of $E > E_{\max}^*$ will drive the stock to extinction. The equilibrium catch as a function of effort and of the biomass as a fraction of K , is shown in Figures 6.1a) and 6.1b).



(a)



(b)

Fig 6.1: Equilibrium catch as a function of fishing effort (a) and of the biomass as a fraction of K (b).

6.2.4 Splitting the year

To better model the dynamics of the stock and of the two fisheries that exploit chokka, the year was divided into two periods, April-December and January-March. The reasons for this split that there is hardly any recruitment during the latter period, and that the jig and trawl catches are disproportionately divided between these two periods. The dynamics of the biomass are thus given by:

$$B_{y+1}^* = B_y e^{-3g/4} + R_y - C_y^{\text{jigA-D}} - C_y^{\text{trawlA-D}} \quad (6.14)$$

$$B_y = B_y^* e^{-g/4} - C_y^{\text{jigJ-M}} - C_y^{\text{trawlJ-M}} \quad (6.15)$$

where B_{y+1}^* is the biomass in year $y+1$ at the start of January,

B_y is the biomass in year y at the start of April,

C_y^{jigJ-M} is the jig catch taken in year y , between January and March,

C_y^{jigA-D} is the jig catch taken in year y , between April and December,

$C_y^{trawlJ-M}$ is the trawl catch taken in year y , between January and March,

$C_y^{trawlA-D}$ is the trawl catch taken in year y , between April and December.

The abundance indices (S^i), which include both the catch per unit effort indices and the biomass estimates from scientific surveys, are assumed for the former to be proportional to the average biomass during the corresponding period:

$$S_y^i = q_i \bar{B}_y e^{\xi_y^i} \quad (6.16)$$

where \bar{B}_y is the average biomass during a given period in year y ,

q_i is the catchability coefficient corresponding to the index i and

ξ_y^i is the observation error corresponding to the index i in year y .

The trawl index for January - March is equal to:

$$(C/E)_y^{trawlJ-M} = q_{trawl} \frac{B_y^* + B_y^* e^{-g/4} - C_y^{jigJ-M} - C_y^{trawlJ-M}}{2} e^{\xi_y^{trawlJ-M}} \quad (6.17)$$

and for April -December is given by:

$$(C/E)_y^{trawlA-D} = q_{trawlA-D} \frac{B_y + R_y + B_{y+1}^*}{2} e^{\xi_y^{trawlA-D}} \quad (6.18)$$

The jig CPUE from April to December is given by:

$$(C/E)_y^{jigA-D} = q_{jigA-D} \frac{B_y + R_y + B_{y+1}}{2} e^{\xi_y^{jigA-D}} \quad (6.19)$$

where $(C/E)_y^{trawlJ-M}$, $(C/E)_y^{trawlA-D}$ and $(C/E)_y^{jigA-D}$ correspond to the catch rates from January to March and April to December of the trawl fishery, and to the catch rate from April to December of the jig fishery.

The biomass estimates from the scientific surveys result from the application of the “swept area” method. This method can be subject to considerable bias in either direction and therefore, little confidence can be placed in the absolute values of those estimates (Augustyn *et al.* 1993), thus are consequently treated collectively as relative indices:

$$S_y^{autumn} = q_{autumn} (B_y + \alpha R_y) e^{\xi_y^{autumn}} \quad (6.20)$$

$$S_y^{spring} = q_{spring} (B_y + R_y) e^{\xi_y^{spring}} \quad (6.21)$$

where S_y^{autumn} is the biomass index from the autumn survey which took place in year y ,

S_y^{spring} is the biomass index from the spring survey which took place in year y ,

α is a fraction between 0 and 1 which was fixed at 0.5 in the base case.

The biomass time-series is estimated by projecting the biomass (B_0) at the start of the catch series forward under the historic annual catches. Assuming that the errors in Equations (6.17) to (6.21) are multiplicative and log-normal with a constant variance (i.e., $S_y^i = q B_y e^{\xi_i}$, $\xi_i \sim N(0; \sigma^2)$), the estimates of the model parameters for recruitment (R), the aggregated parameter g , the biomass at the start of the catch data series (B_0) and the standard deviation of the residuals (σ_i) for each abundance index are obtained by maximizing the appropriate likelihood function. Ignoring constants, this corresponds to minimizing:

$$-\ln L = -\sum_{i=1}^z \ln L_i \quad (6.22)$$

where z is the number of abundance indices and L_i is the likelihood corresponding to

the index of abundance S^i and

$$-\ln L_i = n \ln \sigma_i + \frac{1}{2\sigma_i^2} \sum_{y=1}^{n_i} [\ln S_y^i - \ln \hat{S}_y^i]^2 \quad (6.23)$$

where σ_i is the standard deviation of the residuals, estimated by:

$$\hat{\sigma}_i^2 = \frac{1}{n} \sum_{y=1}^{n_i} (\ln S_y^i - \ln \hat{S}_y^i)^2 \quad (6.24)$$

and n_i is the number of data points for abundance index i . The catchabilities (q_i) are estimated from the following equation:

$$q_i = \exp \left[\frac{1}{n_i} \sum (\ln S_y^i - \ln \bar{B}_y^i) \right] \quad (6.25)$$

where \bar{B}_y^i is the average biomass during the corresponding period in year y . If an estimate of recruitment was too small, resulting in a biomass trajectory which could not sustain the historic catches, a very low value was assigned to the likelihood.

Experimentation on the estimation procedure indicated that the data were not sufficiently informative to allow estimation of all the parameters, so g was fixed externally, with results being evaluated for $g = 1$ and 1.5 (the reasons for these particular choices are discussed in Chapter 5). In subsequent computations it was found that Equation (6.22) yielded a relatively flat minimum, so that it was necessary to introduce the additional constraint that the resource biomass was at pristine equilibrium at the start of the first year of the biomass projections $B_0 = K$, where the year $y = 0$ corresponds to 1971. As a result, the following applies (from the equilibrium solution of Equation 6.1 in the absence of catches):

$$K = B_0 = \frac{R}{(1 - e^{-g})} \quad (6.26)$$

This is an assumption often made when fitting surplus production models with observation-error estimators (Polacheck *et al.* 1993). Furthermore, Punt (1990) found

by simulation for the Cape hake off northern Namibia, even in the cases when B_0 / K was substantially less than unity, that better performance was achieved by fixing it at unity than by estimating it. Sensitivity of the approach developed here to the assumption of $B_0 = K$ was tested by making $B_0 = 0.8 K$ at the time of estimating model parameters. The results in terms of the estimated parameter values showed little sensitivity to changes in this assumption.

6.2.5 Bootstrap estimation of confidence intervals

Replicate data sets were generated by means of conditioned parametric bootstrap procedure to estimate the confidence intervals for the model parameter estimates. Using the abundance indices predicted by the model, random abundance indices were generated, assuming observation error, i.e.:

$$S_y^i = \hat{S}_y^i e^{\xi_y^i} \quad \xi_y^i \text{ from } N(0; \sigma_i^2) \quad (6.27)$$

where \hat{S}_y^i is the estimate of the index of abundance i in year y obtained by fitting the model to the actual data,

$N(0; \sigma_i^2)$ is a normal distribution of mean zero and variance σ_i^2 ,

σ_i^2 is estimated from the residuals of the model fit to the actual data.

The model was then fitted to the artificial data sets and the corresponding estimates of the parameters were stored. Estimates of R which ≥ 20 times the estimate of \hat{R} from the real data, occurred in about 10% of the simulations. These estimates were truncated and made equal to the maximum value considered plausible (500 000). The bootstrap process was repeated 500 times and the bootstrap estimates of the parameters were sorted into ascending order providing estimates of confidence intervals directly.

6.2.6 Projections

The set of parameters R_y^s , q_i^s and σ_i^s estimated from each bootstrap realization were

used to project the resource biomass forward from the most recent biomass estimate, as a starting point. The simulated biomass at the start of January in year $y+1$ is given by:

$$B_{y+1}^{*s} = B_y^s e^{-3g/4} + R_y^s - C_y^{jigA-D^s} - C_y^{trawlA-D^s} \quad (6.28)$$

and the biomass at the start of April in year y was given by:

$$B_y^s = B_y^{*s} e^{-g/4} - C_y^{jigJ-M^s} - C_y^{trawlJ-M^s} \quad (6.29)$$

The simulated annual catch (C_y^s) consists of the total catch taken by the two fisheries during the two periods considered, so that:

$$C_y^s = C_y^{trawlJ-M^s} + C_y^{trawlA-D^s} + C_y^{jigJ-M^s} + C_y^{jigA-D^s} \quad (6.30)$$

The catch for a given fleet, period and year was set by:

$$C_{iy}^s = \min \left\{ \begin{array}{l} \frac{q_i^s E_{iy}}{1 + \frac{1}{2} q_i^s E_y e^{\xi_{iy}^s}} \left[B_y^s \left(\frac{1 + e^{-g}}{2} \right) + R_y^s \right] e^{\xi_{iy}^s} \\ 0.95 (B_y^s e^{-g} + R_y^s) \end{array} \right. \quad (6.31)$$

where ξ_{iy}^s was drawn from $N(0, (\sigma_i^s)^2)$,

E_{iy} is the fishing effort in year y for the fleet-period i and

q_i^s is the estimated catchability for the fleet-period i in simulation s .

The simulated catches for each fishery were computed separately by period and year, from equations derived from (6.31) and given the catchability (q_i^s) and the level of fishing effort E_{iy} corresponding to that fishery and period. The jig January-March CPUE data is included in the likelihood computations but given zero weight – hence the procedure still produces q_i^s and σ_i^s estimates for these indices which are

required to compute the jig January-March catch. The jig effort applied in each period was computed by multiplying the effort level selected for the projections by the proportion of the total jig effort observed in the jig fishery in the last three years during the corresponding period. The trawl annual effort was taken as constant and equal to the average effort observed in the trawl fishery in the last five years. The proportion of that effort corresponding to each period was also estimated from the historic data. The second option in Equation (6.31) is chosen when the calculated catch is larger than $0.95 B$, so to avoid taking all the existing biomass.

6.2.7 Sensitivity tests

A range of sensitivity tests was applied to evaluate the effects of alternative scenarios to that represented in the base case. These alternative scenarios are related either to the data selection or to the model parameters and are as follows:

1. The aggregated parameter g is equal to 1.5. (Base case $g = 1.0$).
2. The value of the threshold (τ) at which recruitment starts declining is equal to 50% of the pristine biomass (K) (Base case $\tau = 0.2$).
3. The time-series of trawl indices of biomass extends from 1978 to 1996 (Base case is 1984 -1996).
4. Six time-series of indices of abundance, including the January-March jig index, are used to assess the status of the chokka resource (Base case excludes the January-March jig CPUE index).

6.3 RESULTS AND DISCUSSION

The model was fitted to the five time-series of biomass indices selected for the base case assessment. Observed and model predictions for each of these series are plotted in Figure 6.2. At first glance, the model predicts an almost flat CPUE trajectory in all cases whereas the observed data show considerable interannual fluctuation, particularly in the case of the commercial CPUE data and autumn survey. Under the modelling approach of this Chapter, these fluctuations are considered to be observation error. An important point to make is that, while the commercial data

suggest a decline in resource abundance, the scientific survey data give a different impression. The spring survey index shows essentially no trend from 1986 to 1995, while the autumn survey suggests an increase from 1989 to 1996, but a decline in 1997. The model fit effectively averages the trends, suggesting a slight decline in the resource biomass since 1984. Although in principle no weights have been given to the various estimates of abundance, by using both: January–March and April–December trawl series, the model has acquired a double weighting on the trawl data. Given the limitations of jig CPUE series, the double weighting could be defensible.

The estimates of the model parameters \hat{R} , \hat{q}_i and $\hat{\sigma}_i$ from the fit to the data ("best estimates"), and the median and the 95% confidence intervals represented by the 2.5th and 97.5th percentiles obtained by bootstrapping, are shown in Table 6.I for the base case. The position of the median relative to the confidence interval bounds indicates skewed distributions in all cases, whereas the best estimates are very close to the median. This is best illustrated by the values presented for recruitment (R) where the median lies relatively close to the low C.I. value. Comparison between the values of σ_i obtained for the different indices suggests that the model best fitted the spring survey index, whereas the index derived from the autumn surveys and the trawl CPUE index were the two fitted with most difficulty.

Results from stochastic 10 year projections are shown in Figure 6.3. The curves represent the median jig catch and the 95% C.I. computed from 500 simulations at increasing levels of jig effort (note that, as explained in the previous section, these computations assume a fixed effort level in the trawl fishery). Each point in the graph represents the median annual catch in 10 years during which effort was kept constant. The indication from this graph is that current jig effort (i.e. about 3600 man hours) is well below the point where maximum catches could be achieved (E_{\max}), which coincides with the level at which biomass is depleted to 20% of K (Figure 6.1). The probability of being below E_{\max} at the current effort level was computed from the projections as equal to 99%.

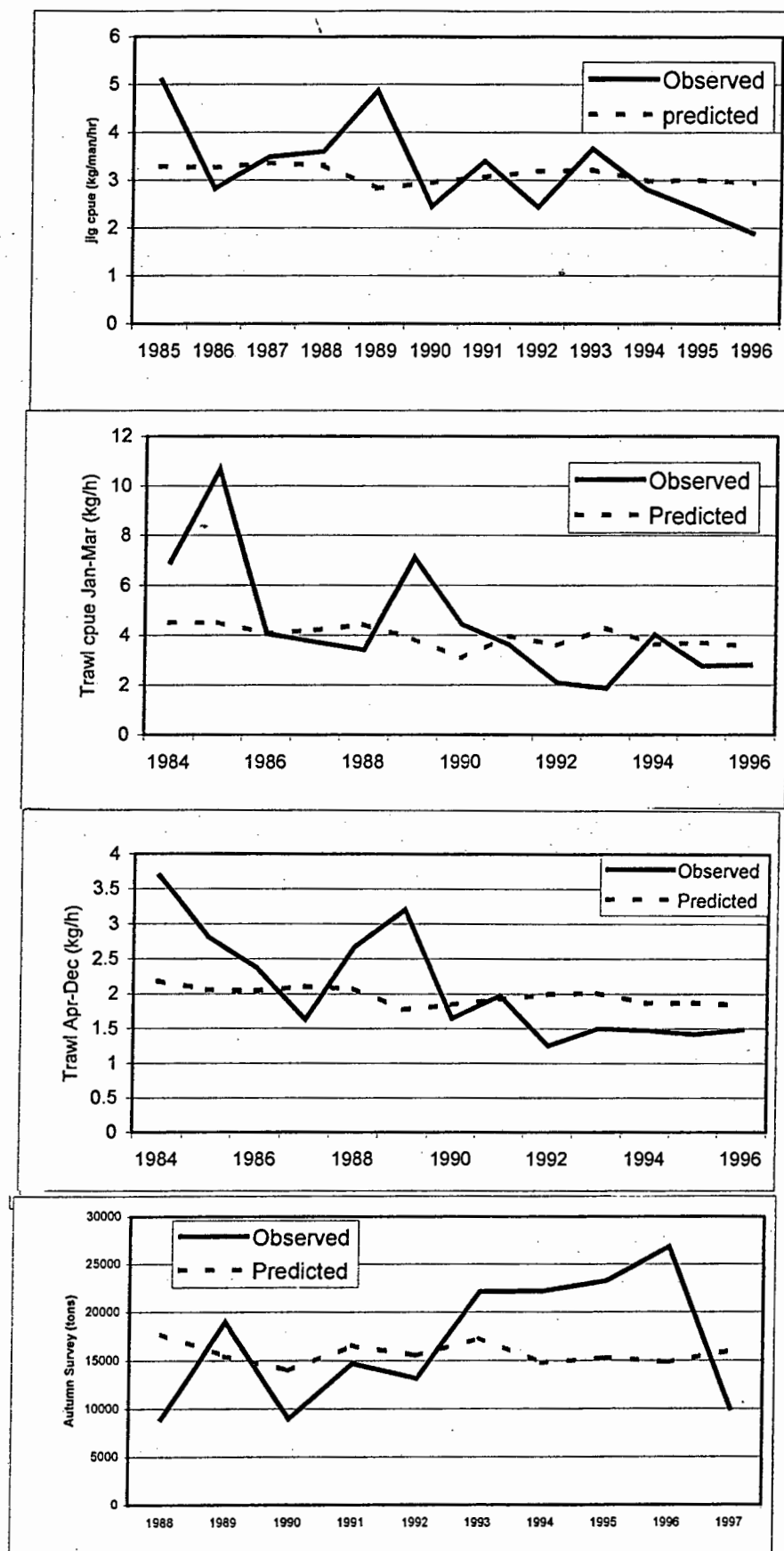


Fig. 6.2: Model fits to five time series of relative abundance indices for the Base case.

Examination of the statistics presented for the base case (Table 6.II), indicate low biological risk associated with the current level of fishing effort. However, the risk associated with the maximum effort (56%) is extremely high compared to the 30% in 20-year projections (equivalent to about 16% over a 10-years period), which is considered an acceptable risk level in the management of the South African anchovy (Butterworth *et al.* 1993). Sensitivity to the estimate of recruitment is explored in Figure 6.4 by means of deterministic biomass projections. An increase in productivity proportional to the increase in recruitment is shown.

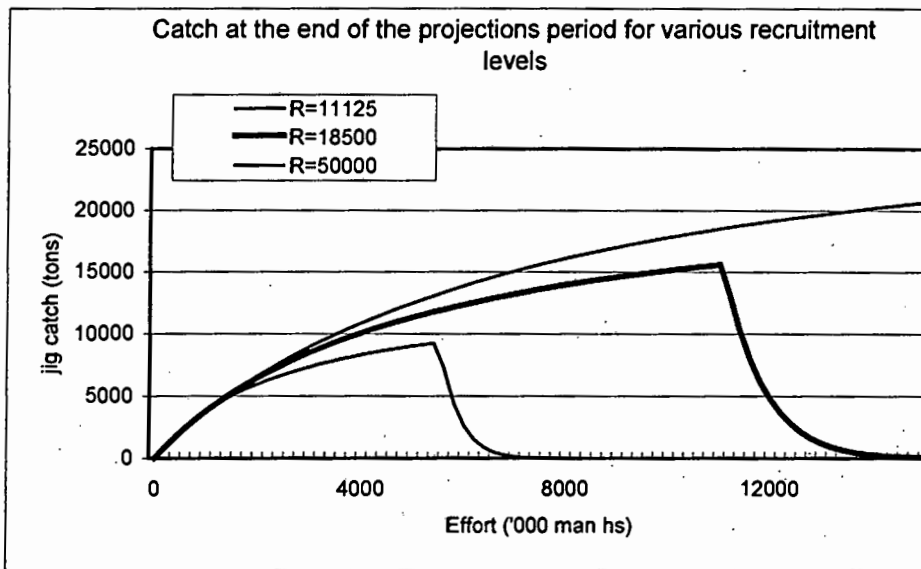


Fig. 6.4: Sensitivity of the sustainable yield level to the estimated recruitment (18 500 tons is the best estimate). Deterministic projections.

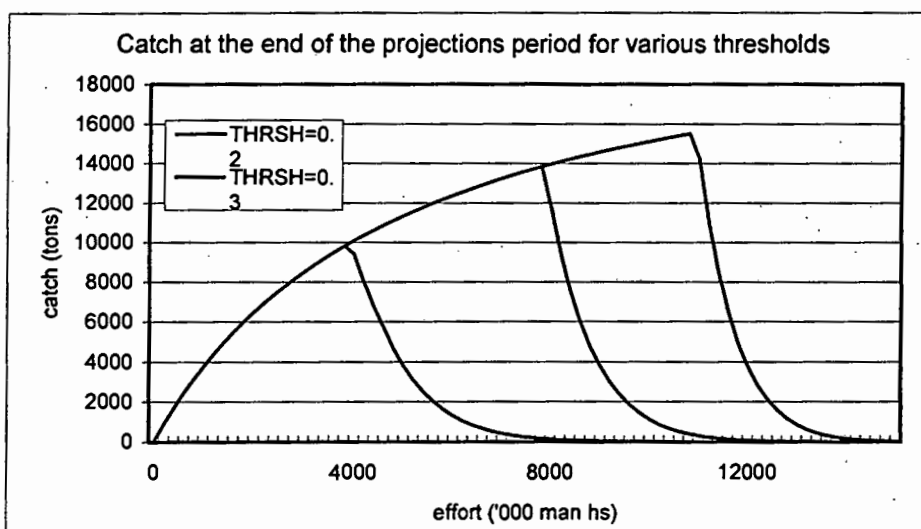


Fig. 6.5: Sensitivity of sustainable yield to the choice of stock-recruit threshold. Deterministic projections.

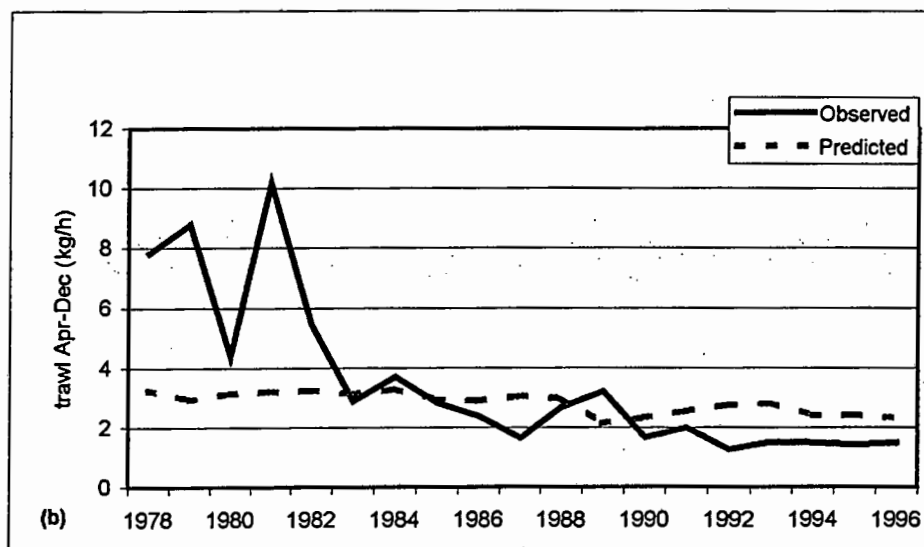
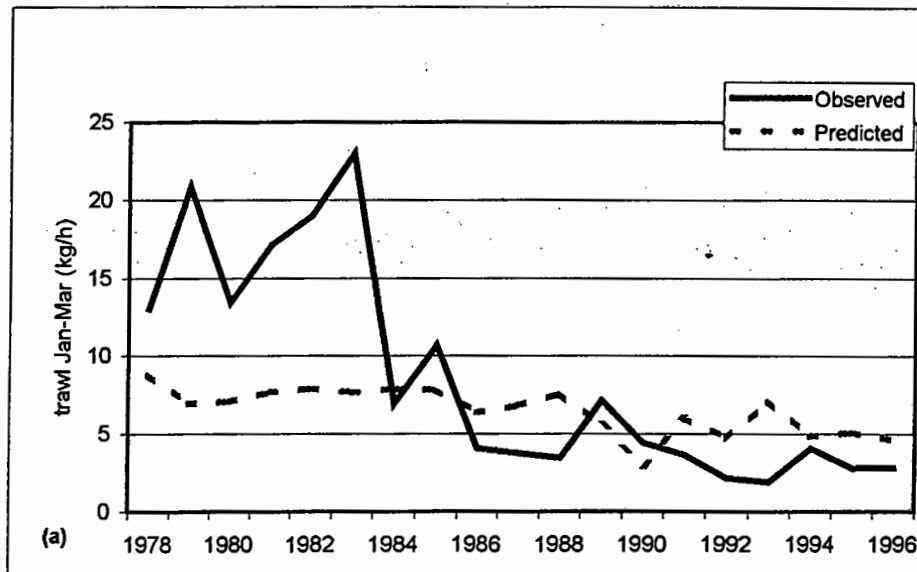


Fig. 6.6: Fit to the complete time-series of trawl CPUE; (a) is the January - March index, and (b) is April - December.

Table 6.I: Estimates of model parameters R (recruitment), q_i (catchability) and σ_i (standard deviation of the residuals), together with the median and 95% confidence intervals (CI), for the base case

Parameter	Estimate	Median	C.I.
R	18500	19125	12718; 500 000
q_{jig}	1.137E-4	9.953E-5	3.07E-6; 2.49E-4
q_{trJ-M}	2.127E-4	2.007E-4	5.19E-6; 5.30E-4
q_{trA-D}	7.121E-5	6.722E-5	2.00E-6; 1.52E-4
q_{Aut}	6.517E-1	4.822E-1	1.68E-2; 1.56
q_{Spr}	4.275E-1	4.167E-1	1.22E-2; 9.00E-1
σ_{jig}	7.501E-2	6.890E-2	2.11E-2; 1.37E-1
σ_{trJ-M}	2.053E-1	1.360E-1	5.62E-2; 3.66E-1
σ_{trA-D}	1.055E-1	8.724E-2	3.02E-2; 1.82E-1
σ_{Aut}	1.725E-1	1.201E-1	4.43E-2; 3.39E-1
σ_{Spr}	5.136E-2	3.892E-2	1.02E-2; 1.03E-1

Table 6.II: Performance statistics estimated in the 10-year projections, under different model scenarios

Data	g	Thres- hold	Max. Yield (tons)	Effort Max (‘000 man-hs)	Risk at Effort Max (%)	Risk at current Effort level (%) ❖	Depletion ★
5 t-s, trawl ind. from 1984 onwards (B.C.)	1.0	0.2	13 884	9 400	56	4	0.54
5 t-s, trawl ind. from 1984 to 1996	1.5	0.2	23 120	17 000	55	2	0.71
5 t-s, trawl ind. from 1978 to 1996	1.0	0.2	7 883	4 500	66	44	0.35
6 time-series, trawl ind. 1978 – 1996	1.0	0.2	36 992	32 000	54	0.2	0.79
5 time-series, trawl index 1984 - 1996	1.0	0.5	8 700	4 200	62	55	0.53
Jig CPUE April - Dec	1.0	0.2	10 546	7 200	56	27	0.48

presented in Chapter 5 based on a process-error estimator are broadly similar. A formal evaluation of the likely biases associated with each approach would require Monte-Carlo testing of alternative estimators specific to this case as performed by Polacheck *et al.* (1993), and is beyond the scope of this work. However, Polacheck *et al.* (1993) concluded that the process-error estimator was both more biased and much less precise than the observation-error estimator. If this indeed applies to the stock studied here, then the results produced in this Chapter should be considered more reliable than those from Chapter 5.

Providing advice on the appropriate level of effort to be applied in this fishery continues to be difficult because the estimates related to the status and productivity of the stock are very imprecise and sensitive to the assumptions made. Notwithstanding those considerations, the results from this study show that the current level of effort is very likely below that corresponding to the maximum catch sustainable even for the most pessimistic scenarios. However, if changes in effort levels were to be recommended on the basis of the results from this study, the following should be considered:

- the level of risk associated with the maximum catch sustainable is high compared to the level that has been considered acceptable for other short-lived species in South Africa;
- the level of risk associated with the current effort level under some of the alternative scenarios investigated is high, indicating the need for cautious management of this valuable resource;
- "The hardest thing to do in fisheries management is reduce fishing pressure" (Hilborn and Walters 1992), i.e. if allowing effort to increase is subsequently found to be inappropriate, it will be a mistake which will be difficult to correct.

The results from the sensitivity tests, particularly those based on the complete trawl CPUE time-series, reflect a sustained decrease in resource abundance and the need to curtail fishing effort in order to halt the decline. However, the fact that the scientific surveys do not confirm this perception weakens a possible recommendation to curtail fishing effort. If nothing else, a recommendation to stop further increases in

CHAPTER 7

Assessment, considering possible negative impacts of the jig fishery's disturbance of spawning aggregations on recruitment

7.1 INTRODUCTION

The sharp decline observed in trawl catches and catch rates of squid in the early eighties has not been explained by the modelling approaches taken in the previous chapter. Yet, informal conversations held with fishermen, confirmed by the results from the analysis presented in Chapter 4, suggest that the decline is genuine and requires explanation. Further, evidence presented in several studies discussed below, focusing on the impact of fishing and/or fishing operations on fish aggregations suggests that the observed decline could be related to the onset of jigging.

In general terms there are a number of population responses to exploitation. They include:

- a decline in abundance of the fished species,
- a contraction of the species' distribution or areas of high density,
- a change in size or age structure, or both, leaving fewer old, large fish,
- an increase in the average growth rate of individuals,
- a reduced age at maturity or size at maturity, or both.

Such responses are often observed in short-lived, fast-growing species according to Clark and Tracey (1994). Those authors have documented the impact of fishing on spawning aggregations of orange roughy, a long-lived species. Although that stock has been labeled over-exploited and there has been a reduction in the number of spawning schools and a marked decline in biomass, the stock showed none of the other signs listed above. Those authors stressed that the fact that orange roughy school to spawn or feed means that large catches can be taken in a short time, and that high catch rates may be maintained despite decreasing biomass. In time, such stocks may become overexploited.

possible disturbances, such as the use of lights or simply the disruption caused by removing individuals involved in a very complex spawning behaviour (Augustyn *et al.* 1994), were not evaluated and in any case would be difficult to quantify. In a more recent study, Sauer (1995) investigated the direct impact of jig fishing operations on chokka squid. His main conclusions were:

- The number of eggs damaged by anchors and anchor chains is currently low (less than 1%), although the number damaged was probably greater in the early years of the fishery (1984-1986), when inexperienced skippers were operating. Sudden changes of weather conditions can result in chains being dragged along the bottom, causing substantial damage to the eggs.
- The presence of large numbers of jigs and vessels appears not to disrupt the overall spawning behaviour.
- Lights do not appear to affect the natural spawning behaviour. At a particular site, the impact of fishing with lights during the night on the abundance of spawning chokka the following day, seems to be confounded with the effect of effectively depleting the spawning concentration by fishing.
- Questions such as whether there is a minimum number of individuals or egg mops required for spawning to take place need further investigation. The associated underlying hypotheses would imply that, at the level of a particular aggregation, spawning or successful spawning would cease completely if abundance falls below a certain threshold.

A scenario in which the onset of jigging operations which target specifically on spawning aggregations has a detrimental effect on subsequent recruitment is modelled in this Chapter. The approach taken does not attempt to model the mechanisms of jigging effects on recruitment. Instead, it consists of a model of the biomass dynamics that includes influences on recruitment levels by a factor proportional to the jig fishing mortality (i.e. the heavier the jig fishing in relative terms, the greater the negative impact on subsequent recruitment success).

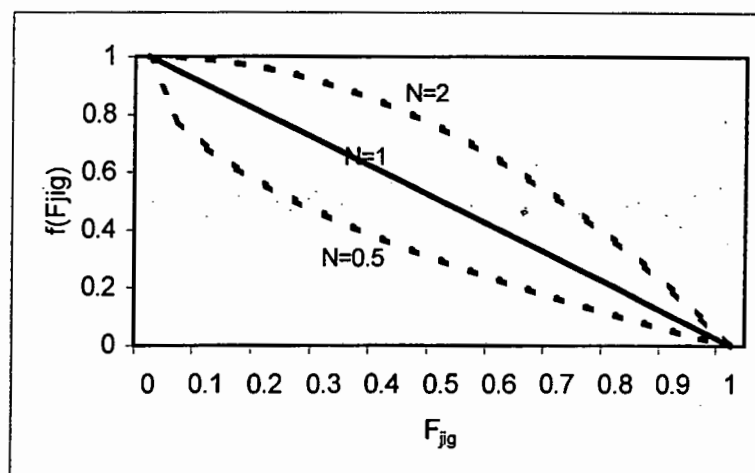


Fig. 7.1: The shape of the $f(F_{jig})$ for various values of N .

The model values of the parameters recruitment R , the catchability q_i and σ_i corresponding to each abundance index i , were estimated by maximum likelihood. The results from Chapter 5 and 6 suggested that the information content of the data would probably not allow estimation of additional parameters. Therefore, the remaining model parameters, the composite parameter g and the stock-recruit threshold τ , were fixed externally in the computations. However, the results from the estimation performed in this Chapter (see Table 7.I) indicated that estimating another parameter could be possible. Therefore, some trials were undertaken to estimate the composite parameter g , the exponent in the function describing the decrease in recruitment due to jig fishing mortality N , the stock-recruit threshold τ and the parameter γ , which defines the relationship between jig CPUE and spawning biomass, in addition to R , q and σ . The initial objective of this exercise was to free the estimation procedure and to explore its performance. The results were used to define the base case and to select alternative parameter scenarios to which sensitivity of the results from the assessments were tested.

The same bootstrapping approach described in Chapter 6 was taken to estimate the 95% confidence intervals for the parameters estimated. The set of parameters R_i^s , q_i^s and σ_i^s estimated from each bootstrap realization were used to project the resource

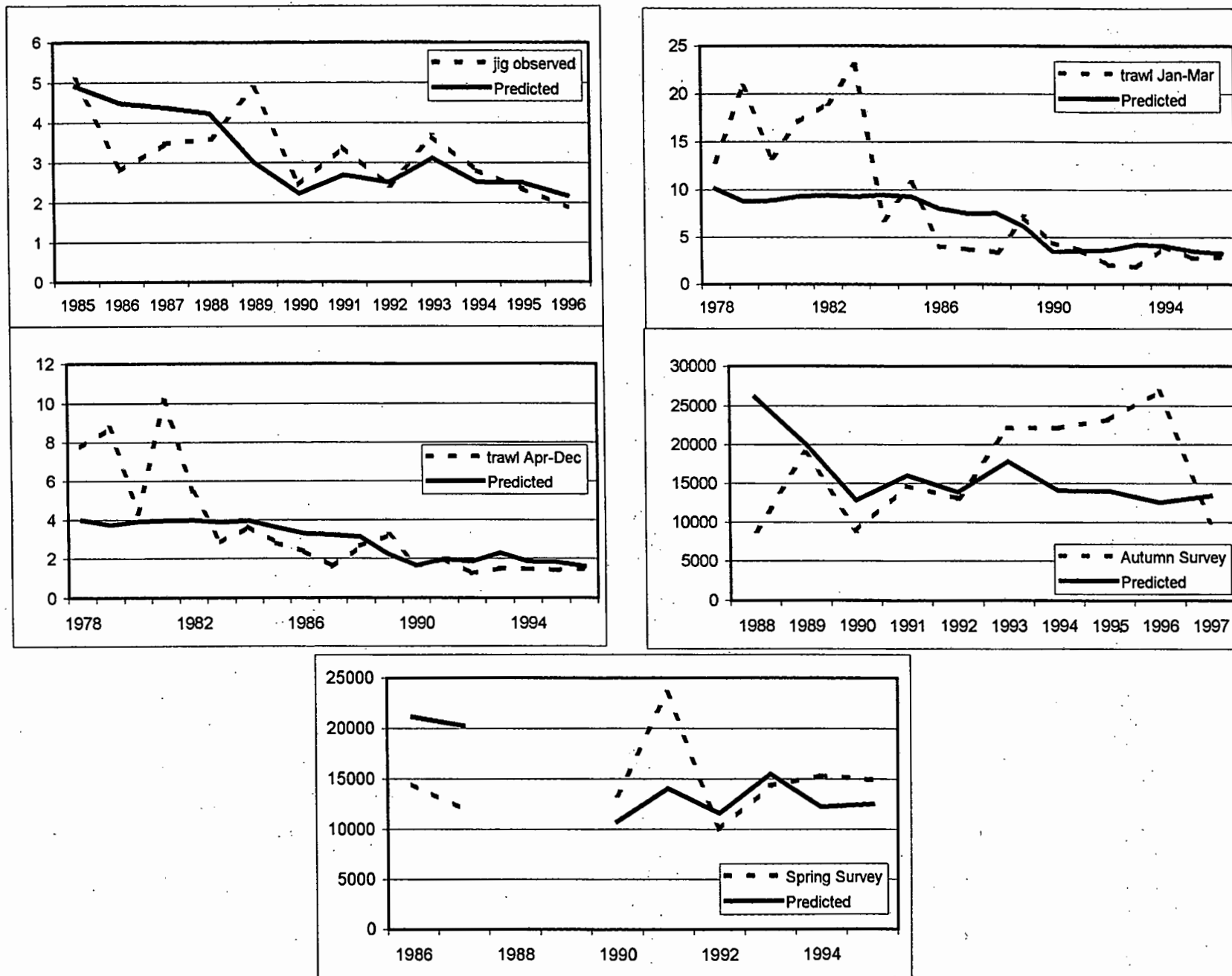


Fig. 7.2: Model fits to the five time-series of abundance indices. Assumptions corresponding to the base case.

Results for separately estimating the values of the parameters g , N , the stock-recruit threshold τ , and γ for situations where all but the parameter estimated are kept at fixed values are shown in Table 7.I. The value of the function minimized (the negative of the log-likelihood) indicates that the fit can be substantially improved by allowing changes to the values of N and γ . However, the procedure estimates a very low value of N , which seems unrealistic. In other words, it fits the early years of the trawl CPUE data by suggesting that even very small levels of jigging induced fishing mortality reduces recruitment by an extremely large factor. Nevertheless, the much improved fits to the trawl CPUE data (compare Figure 6.6 with Figure 7.3) are very suggestive that the disturbance to spawners caused by jig fishing is negatively impacting recruitment even though there may also be other factors, which have not been modelled, that also contribute to the observed CPUE decline. For example, it could be, as suggested by Sauer (1995), that the amount of damage caused by anchor chains was substantial in the early years when the skippers were inexperienced. For simplicity and to avoid making further assumptions, N was made equal to 1 for the base case, and sensitivity was tested for $N = 0.5$. The estimates of γ for $N=1.0$ and $N=0.5$ were 0.57 and 0.58, so it seemed sensible to use $\gamma = 0.5$ for sensitivity tests. A better fit is achieved with a value of the composite parameter g equal to 1, therefore that value was retained for the base case testing sensitivity to $g = 1.5$. The estimate of $\tau = 0.37$ (higher than the base case 0.2) is a reflection of trying to explain the drop in the trawl CPUE when jigging started as a stock-recruitment effect, but little improvement in the log likelihood value is achieved. For reasons explained in Chapter 5, a value of $\tau = 0.2$ was used for the base case and sensitivity was tested to $\tau = 0.5$.

Results from fitting the model for the assumptions corresponding to the base case and for alternatives for the values of parameters N and γ are shown for comparison in Table 7.II. Recruitment estimates for the same value of N hardly differ as γ is changed but the confidence intervals are narrower in the case of square root dependence of CPUE on biomass, corresponding to the significantly better fit to the data for a lower γ value indicated by the log likelihood values in Table 7.I. The value of depletion calculated from the fits to historic data as the ratio of the estimated biomass to the value of pristine (K)

suggest severe depletion, the more so when $\gamma = 0.5$ is assumed. This last scenario reflects the situation that CPUE stays high as abundance drops. It has been named *hyperstability* by Hilborn and Walters (1992), and according to those authors can be expected in almost any fishery where search is highly efficient, so that most effort concentrates on the areas where fish are most abundant, and the fish remain concentrated as abundance declines. Exploitation of organisms in spawning aggregations could therefore be expected to result in hyperstability.

Table 7.II: Parameter estimates for the base case and alternative choices of the parameters N , of the function of the jig fishing rate ($f(F_{jig})$), and γ which describes the relationship between jig CPUE and biomass.

N	g	γ	R_y	95% C.I.	Current Biomass	95% C.I.	Curr. Deplet. (%) \blacktriangle
1.0	1	1.0	16000	15093; 18328	6650	3790; 11763	26
0.5	1	1.0	27375	24844; 33375	12211	7409; 21673	28
1.0	1	0.5	15203	14789; 16500	4211	1851; 7895	18
0.5	1	0.5	25187	23704; 28500	8136	3826; 14101	20

\blacktriangle Current depletion is the ratio of the estimated current biomass to the estimated value of K (pristine).

Table 7.III: Performance statistics for the base case and alternative scenarios for which sensitivity was tested.

N	g	τ	γ	Max Yield (tons)	Corresponding annual effort (thousand man-hours)	Risk* at current level of effort %	Depletion %
1	1	0.2	1.0	5 429	2 900	89	0.09
0.5	1	0.2	1.0	5 750	3 400	69	0.2
1	1.5	0.2	1.0	5 732	3 200	78	0.17
1	1	0.5	1.0	3 473	1 500	100	0.02
1	1	0.2	0.5	4 531	1 800	100	0.00

*The probability that the spawning biomass falls below 20% of its average pristine level at least once during the 10-year projected period

§ Projected depletion, is the ratio of the biomass at the end of 10 yrs projections under the current effort level to the equivalent biomass without fishing.

Results from projecting the resource biomass forward, under a constant effort strategy for 10 years taking the current level of biomass as a starting point, are shown in Table 7.III for the base case and for alternative, plausible parameter scenarios. The risk levels associated with maintaining current effort during a long period (10 years) are extremely high in all cases, and the resource is driven to a very low level at the end of the period, as indicated by the values of depletion. In addition, the yield values indicate a far less productive resource than the levels resulting from the simulations undertaken in Chapter 6. The median catch over 10 years of stochastic projections, together with the corresponding 95% confidence intervals, is plotted in Figure 7.4 for the base case. At the current level of effort, sustainable catches lie within a very wide range, but the upper limit is below the recent catches taken by the jig fishery.

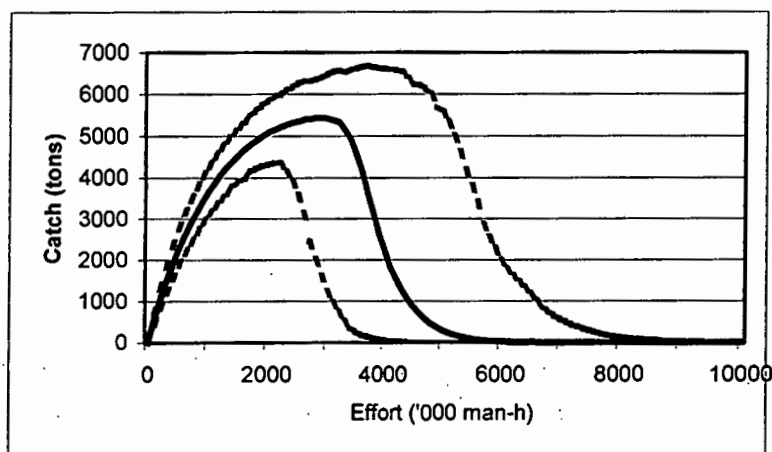


Fig 7.4: Stochastic projections for the assumptions corresponding to the base case.

7.4 CONCLUSIONS

Moving away from the constant recruitment model (or one with a stock-recruit relationship), and making recruitment dependent on the jig fishing mortality to reflect negative impacts on recruitment due to interference effects of the fishing process), results in an improvement in model fit. However, if no constraints are set to moderate such an influence, in order to fit the CPUE in the early 1980s, the model tends to estimate the detrimental impact of jigging on recruitment at levels much higher than would be anticipated from the processes discussed by Sauer (1995) and referred to in the Introduction to this Chapter. It is, however, possible that other processes associated with the jig fishing operation have also played a role in the observed decline.

The current estimated levels of depletion, show a resource close to the base case assumed threshold below which recruitment declines (20% of mean unexploited biomass). This is particularly so if a non-linear (square root) relationship between the jig CPUE and the biomass is assumed. In a similar manner, stochastic biomass projections under current levels of effort suggest that, given the assumptions made for this modelling exercise, the resource is at a high risk of severe biomass reduction. This suggests that unless effort is reduced, the stock is likely to be driven to low levels at which future recruitment will most likely be jeopardized. Chokka is a short-lived species and, therefore, no other older age-classes or pre-recruits are available to buffer the impact that a depleted spawning biomass could have on the following year's recruitment. Basson and Beddington (1993), for the Falkland Islands *Mex* stock, also a short-lived species, argue that the consequences of allowing spawning stock to drop to very low levels can be very serious. Therefore, if the results for the assessment of this chapter are seen to be reliable, management action in the form of jig effort limitation should be instituted sooner rather than later.

The conservation goal in the chokka fishery is to maintain a low level of risk of the spawning biomass falling below some threshold level to avoid high probabilities of very low recruitment in the following year. The management tool currently used to

achieve the conservation goal is effort control. Keeping the effort constant at an optimal level results in harvesting a constant proportion, which is a strategy considered advantageous in short-lived species such as the South African anchovy (Butterworth *et al.* 1993). However, the results from the assessment undertaken in this Chapter suggest that current effort levels can hardly be considered optimal. A target figure of 40% proportional escapement has been advised in the Falkland Islands *Illex* and *Loligo* fisheries (Beddington *et al.* 1990, Agnew *et al.* 1998). An equivalent 40% derived from the stochastic projections for chokka and referred to as depletion, can be attained by reducing the current jig fishing effort from 3 600 to 1 950 man-hours, under the assumptions corresponding to the base case. This level of effort corresponds to 55% of the current deployed and the associated risk (as defined here – see Table 7.III) is 14%. However, reducing fishing effort to such an extent in a political context that attempts to obtain the optimal social and economic benefits from living marine resources and to broaden access to the already exploited marine resources in South Africa, could be very difficult. Nevertheless, a compromise between those seeking access and long term conservation objectives must be reached.

CHAPTER 8

Conclusions and recommendations

8.1 INTRODUCTION

One of the ultimate goals of this thesis is to generate management recommendations for chokka squid based on a rigorous quantitative assessment of the stock. In order to achieve this goal, the following research work was undertaken:

- a review of the species' life cycle; the findings were used to specify pertinent assumptions in the model;
- a detailed examination of the jig fishery, which targets chokka, and of the trawl by-catch fishery;
- evaluation of the abundance indices available: the trawl CPUE, the jig CPUE and the biomass estimates from scientific surveys;
- an application of general linear modelling (GLM) techniques to the trawl data in order to provide an annual index of abundance that is not biased by changes in fishing patterns or composition of the fleet;
- an analysis of the jig CPUE that includes the application of GLM to two years of data for which information on vessel attributes is available;
- development of a biomass-based dynamic model of the stock and fishery dynamics;
- application of the model on a monthly time-scale, to fit the jig CPUE data only;
- application of the model on an annual time-scale to fit four time-series of data: the jig CPUE, the trawl biomass index and the autumn and spring survey estimates of biomass;
- investigation of the stock response to different levels of fishing effort by means of stochastic projections of the resource biomass.

8.2 THE CHOKKA-DIRECTED JIG FISHERY

Despite measures aiming at limiting the fishing effort deployed in the jig industry, the annual effort, measured in total number of man-hours deployed, has gradually increased since the fishery's inception in the early 1980s. This has not so much been the result of an increase in the number of boats participating, but rather the acquisition of new technology which, at the daily level, has resulted in the ability to fish for longer hours, and to operate throughout the year by extending fishing operations beyond the limits of the spawning grounds and into the feeding grounds. These developments have been supplemented by the gradual replacement of small skiboats by larger boats with freezing capacity. Moreover, the larger boats are equipped with sophisticated processing facilities and can offer a better, more marketable product. Therefore, there is great incentive in this fishery to upgrade the vessels into freezer boats. The impact of these developments on the resource was unknown prior to this study, and investigating their effect on the resource and determining the effective effort formed a major aim of this work.

8.3 DATA

8.3.1 *Trawl index of abundance*

The time-series of annual trawl CPUE shows an overall downward trend, with a sharp decline after 1983. In order to get a better understanding and hence interpretation of the trawl fishery data used for this study, the distribution of fishing effort on both temporal and spatial scales was investigated. In addition, the distribution of the CPUE computed either at a drag level or at a daily level (depending on year) was also studied to evaluate the effects of changing fishing patterns, as opposed to changes in resource abundance, on the annual CPUE trend. The results from this exploratory analysis are born out by subsequent application of General Linear Modelling (GLM) techniques to standardise this CPUE series. Some of the results identified as most relevant in terms of the assessment undertaken in this study are as follows.

- The highest catch rates of chokka tend to be in the first three months of the year, in depths which coincide with the main areas of operation of the inshore and offshore hake fleets.
- The time-series of annual abundance derived from the GLM analysis shows a notable decline from 1982 onwards, which is only slightly less pronounced than that indicated by the nominal CPUE.

8.3.2 Jig CPUE

Initial analyses prompted the use of kilograms per man per hour fishing from boats with between 3 and 20 men on board as a measure of catch rate. However, results from a GLM analysis, based on recent years' data for which comprehensive information on vessel attributes is available, suggest that changes over time in the area of operation and the actual size of the fishing vessels could be influential, and therefore that their effects should in future be removed from an index of abundance based on these data. Given the dynamic nature of the chokka fleet, it is therefore recommended that an update of all vessel attributes continues to be collected annually, at the licensing time. Furthermore, a programme to obtain accurate information from the skippers on the position where the jig catches take place, based on a GPS if feasible, should be launched as soon as possible. These data will enable the influence of changes in resource abundance on the CPUE to be separated from other influences, permitting the estimation of a time-series of abundance indices from the directed fishery.

8.3.3 Biomass estimates from scientific surveys

While the autumn survey indicates a modest increase in resource biomass over time (at least until the penultimate data point), the spring survey does not show a clear trend. Qualitative examination of the stock distribution within the survey area did not show changes over time that could be interpreted as the cause of the observed increasing trend in the former series. However, unquantified factors such as increased experience

and ability of the fishing masters enabling them to make positive selection over time of grounds that are trawlable, which may well also be the same grounds preferred by chokka, could have played a role in producing the increasing trend. The highest densities of chokka detected by the autumn surveys are found in water 100 - 200 m deep, offshore of the traditional jig-fishing grounds, whereas the larger concentrations in spring are found inshore of 100 m, coinciding with the species' apparent inshore migration to spawn.

8.4 MODELLING APPROACHES

The assessment has been undertaken on the basis of biomass dynamic models. Two different methods for fitting the models were used.

1. Process-error estimators. The data used were the jig CPUE. The dynamics was modelled on a monthly scale.
2. Observation-error estimators, allowing the simultaneous use of several abundance indices. The data used were the jig CPUE, the CPUE from the trawl by-catch fishery, and two time-series of estimates of biomass from research surveys. The biomass dynamics were modelled over two periods within the year: January - March and April - December, to better simulate the timing of recruitment and of the two fisheries that exploit chokka. Within this approach, two different models were used for annual recruitment R_y :
 - a) recruitment is constant above the biomass threshold at which it starts to decline;
 - b) the recruitment level depends on jig-induced fishing mortality (F_{jig}), larger values of which produce increasingly negative impact on reproductive success.

8.5 STOCK - RECRUITMENT RELATIONSHIP

In the absence of any information showing a relationship between the size of the spawning biomass and subsequent recruitment, the last process is assumed to be constant when the spawning biomass is >20% of its estimated pristine level, and to decline linearly when the spawning biomass is <20% of pristine, as represented in Figure 5.3. The process

error term introduced in Chapter 5 reflects variation about the expected level of recruitment (Equation 5.2). A similar model has been used for management of the Falkland Islands *Illex* fishery (Beddington *et al.* 1990).

When recruitment is directly proportional to the spawning biomass, the model would be called *density-independent*. It infers that the causes of mortality affecting young fish are independent of both how many eggs are produced and to total spawners size. The other extreme corresponds to a relationship called *compensatory* by Hilborn and Walters (1992), which means a reduction of the number of recruits per spawner as the stock size increases. The stock-recruitment curve used in this study becomes flat at stock sizes >20% of pristine (Figure 5.3), i.e. recruitment becomes independent of stock size; it is a classical example of this type of relationship. The number of recruits-per-spawner remains constant until the spawner stock reaches the 20% threshold; thereafter, it declines as the spawning stock increases.

Cochrane and Hutchings (1995), on the basis of a conceptual model of the recruitment process for the South African anchovy *Engraulis capensis*, identified key factors influencing recruitment strength of that stock. Some of the density-dependent mechanisms considered by those two authors are egg cannibalism and competition for food between spawners. It is difficult at this stage to identify the key factors that could be regulating the number of recruits-per-spawner in the case of chokka. Sauer and Smale (1991), in their study on predation patterns on the inshore chokka spawning grounds, concluded that predation by fish on chokka there may be less than intuitively expected. Further, they concluded that cannibalism, a feature investigated by Sauer and Lipiński (1991), may play a greater role in adult squid mortality on the spawning grounds than predation. Seals are another important predator of cephalopods (Lipiński and David 1990), but they are not particularly abundant in the spawning grounds, so their impact on chokka there is likely to be small. Finally, predation on chokka egg masses has been determined to be low (Sauer and Smale 1991).

Environmental conditions are likely to play a major role in all phases of the life cycle of chokka (Roberts and Sauer 1994). According to those authors, severe westerly winds during winter, which cause large swells and in turn elevate turbidity levels near the seabed, will have a negative impact on the occurrence of inshore spawning aggregations. Conversely, an increase in the frequency and severity of easterly winds during summer will increase upwelling frequency and intensity along the coast. The temperature changes that occur during such upwelling events appear to be positively correlated with the abundance of spawning chokka. The effects will act independently of how many eggs or spawners there are, but for a given number of either they will add variability to the expected recruitment.

In overview then,

- there are several mechanisms that play a role in determining recruitment levels in chokka, e.g. predation on the spawners and on eggs, and cannibalism;
- cannibalism is likely to be a density-dependent cause of mortality;
- environmental events such as the frequency of westerly winds in winter and of upwelling events in summer appear to have a direct influence on the extent of spawning inshore.

There will be other mechanisms that can cause mortality on younger stages of the life cycle, i.e. larvae and juveniles, but these have, to date, not been investigated in chokka.

The stock-recruitment relationship assumed in this study, consisting of density-independence at low spawning stock size, and density-dependence represented by constant recruitment, at stock sizes above 20% of pristine, is likely to be a simplification. However, in the face of insufficient information to identify a stock and recruitment relationship, it has been used to model recruitment in other cephalopod stocks (Beddington *et al.* 1991) and for pelagic species such as the South African anchovy (Bergh and Butterworth 1987). Moreover, current knowledge on the mechanisms that could influence recruitment levels does not invalidate the relationship assumed in this study.

8.6 STATUS AND PRODUCTIVITY OF THE RESOURCE

8.6.1 Comparison of results from the process-error and the observation-error estimators

Given the same assumptions for the composite parameter g and the stock-recruit threshold τ , the performance statistics estimated in 10-year projections from the two methods are as follows:

Table 8.I. Performance statistics estimated from 10-year stochastic projections for process-error and observation-error estimators. The assumptions in both cases correspond to the base case.

Performance criteria	Process error	Observation error
Maximum jig yield (tons)	7 708	10 546
Corresponding annual effort (million man-hours)	5.15	7.20
Risk at current effort (%)	76	27
Depletion at current effort (%)	30	48

However, the results of applying these two methods are not exactly comparable (i.e. do not reflect estimation methodology differences alone), for the reasons summarized in Table 8.II.

The performance criteria, maximum yield sustainable and risk associated with current levels of effort (Table 8.I), as derived from the observation-error estimator method, suggest a more productive resource. These differences could be result of the differences listed in Table 8.II. Polacheck *et al.* (1993) found that observation-error estimators result in more precise and less biased parameter estimates and, therefore, if their findings also apply to this chokka resource, the results from the former estimator should be seen as more reliable. However, the estimates of such management-related quantities seem to be sensitive to the selection of an error structure, and this suggests high variance and hence not very

reliable results (Punt and Hilborn 1996). Considering the wide distributions associated with statistics such as the median catch in relation to effort level (see Figure 5.10 and Figure 6.7), this is likely to be the case.

Table 8.II. Main differences between the approaches taken when applying process error and observation error estimators.

Features	Process error	Observation error
Time scale	Monthly	Bi-ennial
Data	<ul style="list-style-type: none"> jig CPUE Jan-Dec jig catches* 	<ul style="list-style-type: none"> jig CPUE Apr-Dec jig and trawl catches
Spawning biomass	Average October-December	December
Recruitment	Monthly pulse from May to December	Pulse in April

* the process error calculation of Chapter 5 concentrated on spawning grounds dynamics and thus ignored trawl catches. Implicitly then those calculations assumed trawl catches to comprise post-spawning squid which would not later return to the spawning grounds.

8.6.2 Observation-error estimator. Comparison of results from the two approaches taken to model recruitment

- Constant recruitment (falling only for spawning biomass below a threshold τ). The results from this assessment are highly imprecise, as shown by the very wide confidence intervals for the model parameter estimates. Faced with five, seemingly incompatible time-series of resource abundance, the results indicate a high level of uncertainty. In addition, the model could not fit the decline observed in the early years of the trawl CPUE index, which resulted in those years having to be eliminated from the base-case.
- Recruitment reduced through the jig fishing operation disturbing the spawning aggregation. This approach achieves the best fit to the four time-series of abundance indices. As a result, the model estimates are more precise than those resulting from the

other approaches and the estimates of the quantities of interest to manage the resource, i.e. performance statistics, are more robust to model assumptions. All these considerations make this assessment the most reliable. The results for the most plausible parameter scenarios show a currently heavily depleted resource, as reflected by the low ratio of the current estimated biomass to its pristine level, and the risk associated with the current level of effort (Tables 7.II and 7.III). Moreover, the estimated maximum yield, as estimated from the stochastic projections, suggests that the resource is less productive than indicated by the constant recruitment models.

In the case of short-lived squid species, the biomass available to the fishery is expected to fluctuate widely because recruitment is a large component of the stock (Pierce and Guerra 1994). Furthermore, fisheries targeting on spawning aggregations can have a negative impact on subsequent recruitment, and therefore on the stock biomass, which will only be detected when the biomass has reached an extremely low level (Hilborn and Walters 1992). Based on such considerations, model b), which models recruitment as a variable depending also on the fishing mortality caused by jigging, is perhaps the more reliable approach.

8.7 MANAGEMENT RECOMMENDATIONS

Chokka is a short-lived species and, as such, will be very sensitive to interannual variability in recruitment. Recruitment variability is large, as indicated by the assessment based on process error (see Chapter 5). For such a stock, a constant proportion management strategy would probably provide the best compromise between maximizing the catches and minimizing interannual variability (Butterworth *et al.* 1993). In the case of chokka, for which no absolute estimates of biomass are available, it seems sensible to use effort control as the management tool to achieve the conservation goal, which is *to maintain a low level of risk of the spawning biomass falling below some threshold level, so as to avoid high probabilities of very poor recruitment in the following year*. However, limiting the number of boat licences issued accordingly may not be sufficient in years

when recruitment is poor. This could happen as a result of factors not related to the dynamics of the fishery, e.g. environmental factors (Roberts and Sauer 1994), which have not been included in the model and could have detrimental effects on recruitment. Therefore, mechanisms both to evaluate such circumstances and to react accordingly, to ensure required levels of escapement, need to be developed.

A key element in this assessment is the uncertainty associated with the estimates of current stock size and associated productivity. This is a feature in almost every fisheries assessment (Francis 1992, Hilborn *et al.* 1993), and the risk levels associated with present levels of fishing effort reflect these fundamental uncertainties. In this study, the risk of "falling below 20% of pristine spawning biomass" has been evaluated over 10-year projections, this period seeming appropriate for a biomass dynamic model applied to a short-lived species. In other words, the system has a "short memory" and (in the absence of recruitment fluctuations) reaches equilibrium in a few years, if effort is kept constant. This biological risk, in turn, needs careful consideration by managers and decision-makers, along with the associated implications for social and economic "risk". Unfortunately, quantitative evaluation of the economic and social risks are not currently available in terms that could make it easy to compare with the biological risk. However, the possibility of income and jobs lost will have to be evaluated, as past experience in South Africa is that short-term objectives of maintaining employment and income often take precedence over the long-term conservation objectives (Cochrane *et al.* 1998).

What is an acceptable level of risk? This question has been answered in different ways by fisheries scientists. Butterworth *et al.* (1997) and Cochrane *et al.* (1998) take both the dynamics of the stock and the reliability of the assessment into account when suggesting acceptable levels of resource risk for the two main pelagic resources (pilchard and anchovy) in South Africa. Higher risks are taken when uncertainty about the abundance measurements is low and when the dynamics of the resource are such that it can be expected to "bounce back" more easily from low levels of biomass. This last scenario corresponds to populations with large recruitment variability, which might drop to low biomass levels even in the absence of exploitation, as a consequence of these

natural fluctuations. Presumably, therefore, such populations would be more resilient to depletion to a certain level than would those with lesser recruitment variability (Butterworth *et al.* 1997). Further, the risk levels accepted in other fisheries of that type (large recruitment variability), 30% for anchovy and 5% for South African sardine over 20-year projection periods (roughly equivalent to 16% and 2.5 % over 10-year projection periods), are chosen in the context of other management goals, such as allowing for a certain amount of growth in the sardine resource, maximizing the catches of the more valuable resource and, at the same time, ensuring a certain level of employment in the reduction fishery (De Oliveira *et al.* 1998). Francis (1993) proposes the definition that a harvesting regime has an acceptable level of risk if the probability that the spawning biomass falls below 20% of pristine is less than 10%, (or equivalently, the percentage of years in which the spawning biomass falls below 20% is less than 10%). However, this may be too conservative for chokka which, being a short-lived species, is probably quite resilient to being reduced to low levels of spawner biomass, and it is possible that it could easily recover from such high levels of depletion (the ratio of current to pristine biomass). However, given the high level of uncertainty in the chokka assessment, there is a need to be cautious, and therefore the adoption of a level of risk lower than that accepted for anchovy seems appropriate.

The long-term response, over 10 years, of the resource to a given level of effort, as estimated from the base case observation error model discussed in Chapter 7, is shown in Figure 8.1 in terms of the associated risk of the spawning biomass falling below 20% of its pristine level. What is clear is that the risk corresponding to conditions of no fishing, i.e. effort = 0, is already 0.13. A non-zero probability of falling below some specified threshold depletion is to be expected in short-lived species which experience large fluctuations in recruitment (Butterworth *et al.* 1993). However, in this case, the main reason for the feature is that the projections commence from the current biomass level, which already is estimated to be only 26% of pristine for the base case (Table 7.II). Therefore, even without fishing, the resource would take a few years to recover to safer levels, so that the probability of dropping below the threshold is enhanced.

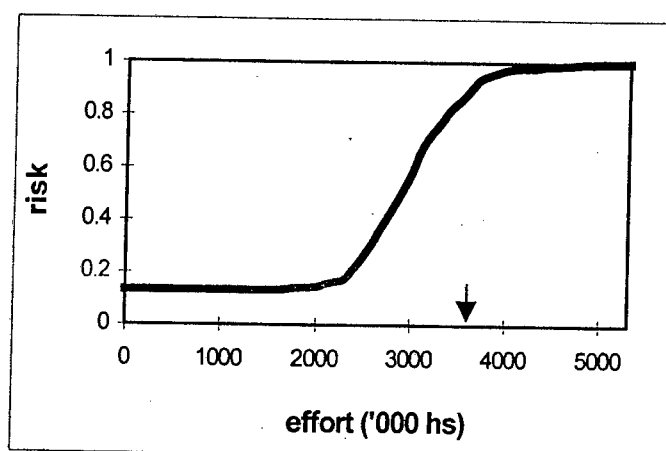


Fig. 8.1: Risk associated with different levels of effort, evaluated from 10-year projections for the assumptions corresponding to the base case model of Chapter 7. The arrow indicates current levels of effort.

Examination of Figure 8.1 suggests that the risk level stays fairly constant until the effort reaches approximately 2 400 units, which corresponds to 2/3 of the current effort deployed with an approximate risk level of 0.2. The median catch and associated 95% probability intervals over 10-year projections, and the corresponding risk levels for three levels of effort relative to the current level, are shown in Table 8.III. Also shown in Table 8.III are the performance statistics corresponding to the more pessimistic scenario, that resulting from the assumption that the jig CPUE is proportional to the square root of the biomass. In this last case, even halving the current effort would result in an extremely high risk and the possibility of total collapse of the resource, indicated by a lower 95% probability limit equal to zero for the estimated median catch.

Given the very serious social and economic implications that effort reductions at the level considered in Table 8.III would certainly have, it seems appropriate to adapt some of the conclusions of Francis (1993), to the circumstances of this assessment to as a word of caution:

Although the probabilities of collapse shown in Table 8.III are the best available, they should not be taken too literally. They indicate, given the assumed life history parameters and the catch history, the probability that a simple biomass dynamic model of the fishery will result in severe stock reductions under different levels of effort. "However, the true risk of fishery collapse is just as likely to be greater than the risks estimated here as it is to be less than them. Thus, it would seem prudent for managers to act as if the true risks are as estimated here."

Table 8.III: Performance statistics: median jig catch and 95% probability intervals and associated risk, for three different jig effort levels expressed in relation to the current level. Results are given both for the assumptions corresponding to the base case, and for the assumption that jig CPUE is proportional to the square root of the biomass ($\gamma = 0.5$).

Jig Effort (relative to current)	Assumptions	Median Jig Catch	95% C.I.	Risk
1	Base Case	4 168	177; 6 649	0.89
2/3	Base Case	5 311	3 928; 6 171	0.21
1/2	Base Case	4 890	4 213; 5 611	0.14
1/2	$\gamma=0.5$	4 531	0; 5 473	0.70

The final decision on what level of risk is acceptable is a political decision, which must consider trade-offs between biological, social and economic considerations. However, this decision needs to be made in full awareness of the implications of Table III. Maintaining the effort at its current level or allowing it to increase carries with it a high risk of severe depletion of the resource within the short to medium-term and the consequent loss of the potential long-term benefits to society from this valuable fishery. A reduction in effort now will unquestionably cause social and economic hardship in the short-term, but will result in the probability that the benefits from the fishery, even if

reduced to some extent, will be sustainable for the foreseeable future and the participants in the fishery will enjoy reasonable security in their livelihood.

8.8 FUTURE WORK

Despite the apparent scarcity of chokka in 1997, when the annual catch hardly reached 3 500 tons, pressure to restructure the industry to allow new-comers into the fishery persists. However, members of the industry have gradually become aware that the pressure on the resource may be excessive already. Suggestions made by representatives of the existing fishing industry indicate that they would be willing to sacrifice some of their profits to reduce effort, but still to accommodate new entrants. The possibility of extending the existing closed season has been mentioned. Precise calculations of the increase in effort represented by each vessel added to the existing fleet would have to be computed per vessel type. This can be done by means of a GLM analysis (Chapter 4). Once the total annual effort represented by the restructured fleet is computed, a shortening of the fishing season, or an extension of the closed season, will have to be debated in line with the effort reductions that result from this study. The way this should be implemented would have to be debated by the interested parties. The final decision will, however, be a political one.

Moreover, a thorough monitoring plan has to be put into place. The plan must include improvements to the information currently submitted by the fishers, as well as finding a means of reporting catch positions accurately.

A range of sensitivity tests to the most important assumptions made in the assessments has been performed in this study. However, an investigation into the sensitivity of the results to other assumptions could strengthen the assessment presented. In other words, there is still room for some "what if..." type of questions that could be worthwhile pursuing. Some examples are the following:

- sensitivity of the results to the choice of months used to estimate mean spawning biomass in Chapter 5;
- choice of the parameter α in Equation 6.20, which relates the autumn survey biomass estimate to the existing biomass.

The methods used in this study to estimate model parameters have either assumed that observation error dominates, i.e. in the relationship between the index of abundance and the biomass (Equations 6.17 - 6.21), or alternatively that the error in the stock dynamics equation (i.e. process error, Equation 5.2) dominates. The results from this study suggest that there is substantial error in both the stock dynamics and the relationship between CPUE and stock abundance. However, there are serious statistical difficulties associated with attempts to incorporate noise occurring simultaneously in both processes (Punt 1991). An appropriate method of incorporating both observation and process error into an estimation procedure is described by Ludwig *et al.* (1988) and was applied by Punt to estimate surplus-production model parameters of the South African hake. Given the results from the assessments presented in this study, there could be merit in examining the feasibility of applying this method to estimation of the model parameters in the approaches taken in this study to assess chokka.

Biological research into clarifying chokka life-span would allow constraint of the number of possible scenarios considered when evaluating the stock response to increasing levels of fishing effort. Similarly, research aimed at identifying the total area of the spawning grounds could be extremely useful at the time of interpreting and evaluating the impact of jigging operations on the stock (Chapter 7).

The “proof” this study offers regarding the jig disturbance reducing recruitment is very indirect – the trawl CPUE drop, which could be the result of something completely different, such as an environmental shift leading to lower recruitment levels than in the past. Some efforts need to be made to seek independent verification of this effect. An independent verification could be provided by birthday distribution curves based on daily

ageing data which, if this effect was real, would show that a disproportionate fraction of the recruits were born from eggs deposited during the closed season period.

There is currently little confidence in the stock recruitment relationships used to establish biological reference points in other cephalopod fisheries (Basson and Beddington 1993, Agnew *et al.* 1998). In the case of chokka the following research objectives are suggested in relation to the stock recruitment relationship and its implication for management:

- to obtain absolute estimates of the stock biomass by means of acoustics would certainly constrain the model estimates, and these data could be used in turn to investigate the stock-recruit relationship.
- to estimate a 'safe' level of recruitment for chokka;
- to develop techniques to assess recruitment strength as the fishing season progresses;
- to investigate additional mechanisms that could be implemented to ensure that enough spawning takes place in years when recruitment levels are very low; i. e. effort could be reduced by adjusting the length of the closed season in proportion.

Moreover, meeting some of these research objectives would result in a meaningful contribution to the global understanding of cephalopod dynamics.

8.9 CONCLUSION

The main question addressed herein relates to the title of this thesis, namely an assessment of the status and productivity of the chokka resource. Based on different assumptions regarding the dynamics and the predominant type of error, several models and estimation methods have been applied and the results are presented in Chapters 5, 6 and 7. However, the results are not always consistent and a range of scenarios emerge regarding the status and productivity of the chokka resource. The scenarios can be interpreted as risky or optimistic, or as more conservative or pessimistic, depending on which extreme of the scenarios is considered. A semi-qualitative description of the

properties that define the status and productivity of chokka for the two extreme scenarios (for the assumptions corresponding to the base case), are shown in Table 8.IV:

Table 8.IV: Status and productivity of the chokka resource according to the more conservative and more risky scenarios.

Property	Risky scenario	Conservative scenario
Current level of exploitation relative to jig E_{max}	Underexploited	Overexploited
Depletion at current effort level relative to pristine (%)	Low	Even lower
Risk associated with current jig effort level in relation to that accepted for anchovy	Very high	Very high
Sensitivity to main assumptions	Sensitive	Less sensitive
Maximum sustainable jig catches, relative to the past average	Slightly above	Slightly below

Given the uncertainty relative to the current level of exploitation of the chokka resource, it seems appropriate to invoke the application of a precautionary approach, which calls for prudent foresight and priority to be given to conservation of the resource under circumstances where the impact of fisheries on the resource is uncertain (F.A.O. 1995). That would be in line with the sentiments expressed in South Africa's new marine fisheries policy (Anon. 1997). However, and in view of the high risk levels of risk associated with the current effort level and the sensitivity of the results to the main assumptions, the possibility of reducing the current level of effort should be considered.

Hypotheses

A number of hypotheses were listed in Chapter 1. Some of them were investigated, and either accepted or rejected, on the basis of the results from the GLM:

- that the decline in the nominal trawl CPUE in the early 1980s reflects a real decline in the trawlers' by-catch of chokka and is not the result of changes in fishing patterns, strategy and/or fleet composition;

The hypothesis that the closed season, as it stands at present, contributes substantially to the conservation and utilization of chokka was tested by the assessment undertaken in Chapter 5. The results showed that, given the assumptions made in the model,

- at current effort levels, the closed season contributes only marginally to the conservation and better utilization of the chokka;
- the closed season represents a reduction in total annual effort of about 9%.

(Although that cut in effort may be considered small, it is recommended that the closed season be retained as a tool to reduce effort even further, if such is required.)

Other hypotheses were examined by assuming that they represent real features of the resource dynamics, formulating a biomass-based model consistent with those hypotheses, and then assessing how well the model could fit the data available. The results indicate:

- that the dynamics of the fishery and the stock can be captured in a simple biomass-based dynamic model. Biomass dynamic models of the types presented in Chapter 5, 6 and 7 can fit the data available for the chokka fishery, but research does not show that some alternative assessment may equally well explain the observed pattern;
- that the decline in the trawlers' catch rate is caused by the jig fishery removing the biomass that otherwise would contribute to recruitment to the trawl fishery. This hypothesis was tested by the modelling approach undertaken in Chapter 6, the results suggesting that the quantities taken by the jig fishery were not, however, alone sufficient to cause that decline.

- that the jig fishery “disturbs” the spawning process and causes a decline in subsequent recruitment. Therefore, as stated above, the decline in the trawlers’ catch rate would be the result of a decline in the recruitment level. This hypothesis was tested by the modelling approach developed in Chapter 7. The results showed that this hypothesis is more consistent with the data than that addressed in Chapter 6.

Overall, this thesis brings together relevant aspects of existing knowledge on the biology, distribution and behaviour of chokka with data available from the fishery. By doing so within the framework of assessment models, the study makes a contribution to a better understanding of the dynamics of the fishery and of the response of chokka to alternative management options selected in the context of a constant proportion harvesting strategy.

LITERATURE CITED

- AFRICAN NATIONAL CONGRESS 1994 - *Draft Policy for Management and Development of the Marine Resources of South Africa* (May 1994): 10 pp.
- AGNEW, D. J., BARANOWSKI, R., BEDDINGTON, J. R., DEL CLERS, S. and C. P. NOLAN 1998 - Approaches to assessing stocks of *Loligo gahi* around the Falkland Islands. *Fish. Res.* **35**(3): 155-169.
- AGNEW, D. J., NOLAN, C. P. and S. DES CLERS 1998 - On the problem of identifying and assessing populations Falkland Island squid *Loligo gahi*. In *Cephalopod Biodiversity, Ecology and Evolution*. Payne, A. I. L., Lipinski, M. R., Clarke, M. R. and M. A. C. Roeleveld (Eds). *S. Afr. J. mar. Sci.* **20**: (in press).
- ANON. 1997 - *White Paper. A Marine Fisheries Policy for South Africa*. [Cape Town; Department of Environmental Affairs and Tourism]: 146 pp.
- AUGUSTYN, C. J. 1989 - Systematics, life cycle and resource potential of the chokker squid *Loligo vulgaris reynaudii*. Ph.D. thesis, University of Port Elizabeth: xi + 378 pp.
- AUGUSTYN, C. J. 1990 - Biological studies on the chokker squid *Loligo vulgaris reynaudii* (Cephalopoda: Myopsida) on spawning grounds off the south-east coast of South Africa. *S. Afr. J. mar. Sci.* **9**: 11-26.
- AUGUSTYN, C. J., LIPINSKI, M. R. and W. H. H. SAUER 1992 - Can the *Loligo* squid fishery be managed effectively? A synthesis of research on *Loligo vulgaris reynaudii*. *S. Afr. J. mar. Sci.* **12**:903-918.
- AUGUSTYN, C. J., LIPINSKI, M. R., SAUER, W. H. H., ROBERTS, M. J. and B. A. MITCHELL-INNES 1994 - Chokka squid on the Agulhas Bank: life history and ecology. *S. Afr. J. Sci.* **90**(3): 143-154.

- AUGUSTYN, C. J. and B. A. ROEL (in press) - Fisheries biology, stock assessment and management of the chokka squid *Loligo vulgaris reynaudii* in South African waters: an overview. *Proceedings of CalCOFI Workshop*.
- AUGUSTYN, C. J., ROEL, B. A. and K. L. COCHRANE 1993 - Stock assessment in the chokka squid *Loligo vulgaris reynaudii* fishery off the coast of South Africa. In *Recent Advances in Cephalopod Fisheries Biology*. Okutani, T., O'Dor, R. K. and T. Kubodera (Eds). Tokyo; Tokai University Press: 3-14.
- BASSON, M. and J. R. BEDDINGTON 1993 - Risks and uncertainties in the management of a single-cohort squid fishery: the Falkland Islands *Illex* fishery as an example. In *Risk Evaluation and Biological Reference Points for Fisheries Management*. Smith, S. J., Hunt, J. J. and D. Rivard (Eds). *Can Spec. Publ. Fish. aquat. Sci.* **120**: 253-259.
- BASSON, M., BEDDINGTON, J. R., CROMBIE, J. A., HOLDEN, S. J., PURCHASE, L. V. and G. A. TINGLEY 1996 - Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the Southwest Atlantic as an example. *Fish. Res.* **28**: 3-27.
- BADENHORST, A. and M. J. SMALE 1991 - The distribution and abundance of seven commercial trawlfish from the Cape south coast of South Africa, 1986-1990. *S. Afr. J. mar. Sci.* **11**: 377-393. {PRIVATE }
- BEDDINGTON, J. R., ROSENBERG, A. A., CROMBIE, J. A. and G. P. KIRKWOOD 1990 - Stock assessment and the provision of management advice for the short fin squid fishery in Falkland Islands waters. *Fish. Res.* **8**: 351-365.
- BEVERTON, R. J. H and S. J. HOLT 1957 - On the dynamics of exploited fish populations. *Fish. Invest. Ser. 2*, Vol. 19. Ministry of Agriculture and Fisheries, London.

- BRODZIAK, J. K. T. and A. A. ROSENBERG 1993 - A method to assess squid fisheries in the north-west Atlantic. *ICES J. mar. Sci.* **50**: 187-194.
- BRODZIAK, J. K. T and W. K. MACY III 1996 - Growth on long-finned squid, *Loligo pealei*, in the northwest Atlantic. *Fish. Bull.* **94**: 212-236.
- BROWN, J. P. 1996 - Results from further sensitivity analysis for the west coast hake. *Internal Report, Sea Fisheries Research Institute WG/10/96/D:H:35*: 4 pp.
- BROWN, J. P. 1998 - The application of general linear modelling for determining trends in abundance for the hake and rock lobster stocks off Southern Africa. M.Sc. thesis, University of Cape Town: 193 pp. (submitted).
- BUTTERWORTH, D. S. 1988 - A critique of "Dynamic models for TAC assessment: logic, potentialities, development" by V. K. Babayan and Z. I. Kizner. *Colln scient. Pap. int. Commn SE. Atl. Fish.* **15**(1): 85-98.
- BUTTERWORTH, D. S., DE OLIVEIRA, J. A. A. and K. L. COCHRANE 1993 - Current initiatives in refining the management procedure for the South African anchovy resource. In *Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations, Anchorage, October 1992*. Kruse, G., Eggers, D. M., Marasco, R. J., Pautzke, C. and T. J. Quinn (Eds). Fairbanks, Alaska; Sea Grant College Program: 439-473 (Alaska Sea Grant College Report **93-102**).
- BUTTERWORTH, D. S., DE OLIVEIRA, J. A. and K. L. COCHRANE 1993 - Current Initiatives in Refining the Management Procedure for the South African Anchovy Resource. 439-473.
- BUTTERWORTH, D. S., COCHRANE, K. L. and J. A. A. DE OLIVEIRA 1997 - Management procedures: a better way to manage fisheries? the South African experience. In Pikitch, E. K., Huppert, D. D. and M. P. Sissenwine. (Eds). *Global Trends: Fisheries Management. Am. Fish. Soc. Symp.* **20**: 83-90.

- CADDY, J. F. 1983 – The cephalopods: factors relevant to their population dynamics and to the assessment and management of stocks. In: J. F. Caddy (Editor), *Advances in Assessment of World Cephalopod Resources*. Caddy, J. F. (Ed.) *FAO Fish. tech. Pap.* **231**: 416-449.
- CADDY, J. F. and R. MAHON 1995 – Reference points for fisheries management. *FAO Fish. tech. Pap.* **347**: p. 83.
- CLARK, C. W., CHARLES, A. T., BEDDINGTON, J. R. and M. MANGEL 1985 - Optimal resource capacity decisions in a developing fishery. *Mar. Resource Econ.* **2**(1): 25-53.
- CLARK, M. R. and D. M. TRACEY 1994 – Changes in a population of orange roughy, *Hoplostethus atlanticus*, with commercial exploitation on the Challenger Plateau, New Zealand. *Fishery Bull., Wash.* **92**(2): 236-253[B1].
- COCHRANE, K. L. and L. HUTCHINGS 1995 – A structured approach to using biological and environmental parameters to forecast anchovy recruitment. *Fish. Oceanogr.* **4**(2): 102-127.
- COCHRANE, K. L., BUTTERWORTH, D. S., DE OLIVEIRA, J. A. A. and B. A. ROEL 1998 – Management procedures in a fishery based on highly variable stocks and with conflicting objectives: experiences in the South African pelagic fishery. *Revs Fish Biol. Fish.* **8**: 177-214.
- COCHRANE, K. L., BUTTERWORTH, D. S. and A. I. L. PAYNE 1997 - South Africa's offshore living marine resources: the scientific basis for management of the fisheries. *Trans. R. Soc. S. Afr.* **52**(1): 149-176.
- COCHRANE, K. L. and A. I. L. PAYNE 1998 - People, purses and power: the role of policy in directing fisheries management as indicated by the debate surrounding a developing fisheries policy for South Africa. *Revs Fish Biol. Fish.*

- CUSHING, D. H. 1968 - A Study in Population Dynamics. Univ. Wisconsin Press, Madison, Wisconsin.
- DE OLIVEIRA, J. A. A., BUTTERWORTH, D. S., ROEL, B. A., COCHRANE, K. L. and J. P. BROWN 1998 - The application of a management procedure to regulate the directed and bycatch fishery of the South African Sardine. *S. Afr. J. mar. Sci.* **20**: (in press).
- DES CLERS, S. 1997- Trawling for *Loligo gahi* on the shelf edge in Falkland Islands waters: hoovers on a sliding carpet? Abstracts *CLAC International Symposium and Workshops: Cephalopod Biodiversity, Ecology and Evolution*.
- EFRON, B. 1981 - Nonparametric estimates of standard error: the jackknife, the bootstrap and other methods. *Biometrika* **68**(3): 589-599
- EFRON, B. 1982 - The jackknife, the bootstrap and other resampling plans. Society for Industrial and Applied Mathematics. Philadelphia. 92 p.
- EFRON, B. 1985 - Bootstrap confidence intervals for a class of parametric problems. *Biometrika* **72**: 45-58.
- F.A.O. 1995 - Precautionary approach to fisheries. 1. Guidelines on the precautionary approach to capture fisheries and species introductions. *F.A.O. Fish. tech. Pap.* **350**(1): 52 pp.
- FRANCIS, R. C. C. 1992 - Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. *Can. J. Fish. aquat. Sci.* **49**: 922-930.
- FRANCIS, R. C. C. 1993 - Monte Carlo evaluation of risks for biological reference points used in New Zealand fishery assessments. In *Risk Evaluation And Biological Reference Points For Fisheries Management*. Smith, S. J., Hunt, J. J. and D. Rivard. (Eds). *Can. Spec.. Publ. Fish. aquat. Sci.* **120**: viii + p. 442.

- FRANCIS, R. I. C. C. and R. SHOTTON 1997 – "Risk" in fisheries management: a review. *Can. J. Fish. aquat. Sci.* **54**(8): 1699-1715.
- GOMEZ-MUYOZ, V. M. 1990 – A model to estimate catches from a short fishery statistics survey. *Bull. Mar. Sci.* **46**(3): 719-722
- GULLAND, J. A. 1983 – *Fish Stock Assessment: a Manual of Basic Methods*. New York; Wiley: 223 pp.
- GULLAND, J. A. 1956 - On the fishing effort in English demersal fisheries. *Tech. Rep. Environ. Can. fish. Mar. Serv.* **690**: 63 pp.
- HATANAKA, H., SATO, T., AUGUSTYN, C. J., PAYNE, A. I. L. and R. W. LESLIE. 1983 – Report on the Japan/South Africa joint trawling survey on the Agulhas Bank in November/ December 1980. *Spec. Publ. mar. fish. Resource Cent.*: 73pp.
- HILBORN, R., PIKITCH, E. K. and R. C. FRANCIS 1993 – Current trends in including risk and uncertainty in stock assessment and harvest decisions. *Can. J. Fish. aquat. Sci.* **50**: 874-880.
- HILBORN, R. and C.J. WALTERS 1992 - *Quantitative Fisheries Stock Assessment. Choice, dynamics & uncertainty*, London:Chapman and Hall, 1992: 1-570.
- JAPP, D. W., SIMS, P. F. and M. J. SMALE 1994 – A review of the fish resources of the Agulhas Bank. *S. Afr. J. Sci.* **90**(3): 123-134.
- KIMURA, D. J. 1981 – Standardized measures of relative abundance based on modelling log (*cpue*), and their application to Pacific ocean perch (*Sebastes alatus*) *J. Cons. int. Explor. Mer* **39**: 211-218.
- KIRKWOOD, G. P. 1981 – Estimation of stock size using relative abundance data – a simulation study. *Rep. int. Whal. Commn.* **42**: 595-644

- LANGE, A. M. 1991 – Alternative survey indices for predicting availability of longfin squid to seasonal northwest Atlantic fisheries. *N. Am. J. Fish. Mgmt* 11: 443-450.
- LIPÍŃSKI, M. R. and DAVID, J. H. M. 1990 – Cephalopods in the diet of the South African fur seal (*Arctocephalus pusillus pusillus*). *J. Zool., Lond.* 221: 359-374.
- LIPÍŃSKI, M. R. 1994 - Differences among basic biological parameters in a population of chokka squid *Loligo vulgaris reynaudii* (cephalopoda:loliginidae) sampled by three methods. *S. Afr. J. mar. Sci.* 14: 281-286.
- LIPÍŃSKI, M. R. and M. D. DURHOLTZ 1994- Problems associated with ageing squid from their statoliths: towards a more structured approach. *Antarctic Sci.* 6(2): 215-222.
- LIPÍŃSKI M. R., AUGUSTYN, C.J., BRODZIAK, J. K. T., BUTTERWORTH D. S., CHRISTY G., DES CLERS S., JACKSON G., O'DOR R., PAULY D., PURCHASE L., ROBERTS, M. J., ROEL, B. A., SAKURAI, Y. and W. H. H. SAUER. 1998 - Cephalopod fisheries: a future global upside to past over-exploitation of living marine resources exploitation. Results of an international workshop, 31 August - 2 September 1997, Cape Town, South Africa *S. Afr. J. mar. Sci* 20:
- LIPÍŃSKI, M. R., DURHOLTZ, M. D. and L. G. UNDERHILL 1998 - Field validation of age from the statoliths of chokka squid *Loligo vulgaris reynaudii* D'Orbigny, 1845 and an assessment of associated errors. *ICES J. mar. Sci.* 55:
- LLUCH-BELDA, D., CRAWFORD, R. J. M., KAWASAKI, T., MACCALL, A. D., PARRISH, R. H., SCHWARTZLOSE, R. A. and P. E. SMITH 1989 – World-wide fluctuations of sardine and anchovy stocks: the regime problem. *S. Afr. J. mar. Sci* 8: 195-205.

- LUDWIG, D. and C. J. WALTERS 1989 – A robust method for parameter estimation from catch and effort data. *Can. J. Fish. aquat. Sci.* **46**: 187-144.
- LUDWIG, D., WALTERS, C. J. and J. COOKE 1988 – Comparison of two models and two estimation methods for catch and effort data. *Nat. Resour. Model.* **2**(3): 457-498.
- MANGOLD-WIRZ, K. 1963 - Biologie des cJphalopods bentiques et nectoniques de la Mer Catalane. *Vie Milieu Suppl.* **13**: 285 pp. + 4 Plates + 2 Charts.
- McALLISTER, M. K., PIKITCH, E. K., PUNT, A. E. and R. HILBORN 1994 – A Bayesian approach to stock assessment and harvest decisions using the sampling/importance resampling algorithm. *Can. J. Fish. aquat. Sci.* **51**: 2673-2687.
- MELO, Y. C. and W. H. H. SAUER 1998 – A description of a ovarian atresia in cephalopods. *S. Afr. J. mar. Sci.* **20**: (in press).
- MONTEVECCHI, W. A. 1993 – Seabird indication of squid stock conditions. *J. Cephalopod Biol.* **2**(2): 57-63.
- NELDER, J. A. and R. MEAD 1965 – A simplex method for function minimization. *Comput. J.* **7**: 308-313.
- OOSTHUISEN, A. 1998 – M.Sc. thesis, University of Port Elizabeth
- PAULY, D. 1980 - On the interrelationships between natural mortality, growth, parameters and mean environmental temperature in 175 fish stocks. *J. Cons. perm. int. Explor. Mer* **39**(2): 175-192.
- PAULY, D. 1985 - Population dynamics of short-lived species, with emphasis on squids. *NAFO Scient. Coun. Stud.*, **9**: 143-154.

- PAULY D. 1998 - Why squid, though not fish, may be better understood by pretending they are. *S. Afr. J. mar. Sci* 20: (in press)
- PAYNE, A. I. L. 1989 – Cape hakes. In *Oceans of Life off Southern Africa*. Payne, A. I. L. and R. J. M. Crawford (Eds). Cape Town; Vlaeberg: 136-147.
- PAYNE, A. I. L., BADENHORST, A., AUGUSTYN, C. J. and R. W. LESLIE 1989 – Biomass indices for Cape hake and other demersal species in south African waters in 1988 and earlier. *Colln scient. Pap. int. Commn SE. Atl. Fish.* 16(2): 25-62.
- PAYNE, A. I. L. and R. J. M. CRAWFORD 1989 - The major fisheries and their management. In *Oceans of Life off Southern Africa*. Payne, A. I. L and R. J. M. Crawford (Eds). Cape Town; Vlaeberg: 50-61.
- PAYNE, A. I. L., LESLIE, R. W. and C.J. AUGUSTYN 1984 - Hake stock assessments in ICSEAF Division 1.6 and 2.1/2.2. *Colln scient. Pap. int. Commn SE. Atl. Fish.* 11(2): 23-33.
- PIERCE, G. J. and A. GUERRA 1994 - Stock assessment methods used for cephalopod fisheries. *Fish. Res.* 21: 255-285.
- POLACHECK, T, HILBORN R. and A. E. PUNT 1993 – Fitting surplus production models: comparing methods and measuring uncertainty. *Can. J. Fish. aquat. Sci.* 50: 2597-2607.
- PUNT, A. E. 1990 – Is $B_1 = K$ an appropriate assumption when applying an observation error production-model estimator to catch-effort data? *S. Afr. J. mar. Sci.* 9: 249-259.
- PUNT, A. E. 1991 – Management procedures for Cape hake and baleen whale resources. Ph.D. thesis, University of Cape Town: 875 pp.

- PUNT, A. E. and D. S. BUTTERWORTH 1993 - Variance estimates for Fisheries assessment: their importance and how best to evaluate them. In: *Risk Evaluation And Biological Reference Points For Fisheries Management*. Smith, S.J., Hunt, J.J. and Rivard, D. (Eds). *Can. Spec. Publ. Fish. aquat. Sci.* **120**:
- PUNT, A. E. and R. HILBORN 1996 - Biomass dynamic models. User's manual. *F.A.O. Computerized Inf. Ser. (Fisheries)*. **10**: 62 pp.
- ROBERTS, M. R. and W. H. H. SAUER 1994 - Environment: the key to understanding the South African chokka squid (*Loligo vulgaris reynaudii*) life cycle and fishery? *Antarctic Sci.* **6**(2): 249-258.
- ROSENBERG, A. A., G. P. KIRKWOOD, J. A. CROMBIE and J. R. BEDDINGTON 1990 - The assessment of stocks of annual squid species. *Fish. Res.* **8**: 335-350.
- SATO, T. and H. HATANAKA 1983 - A review of assessment of Japanese distant-water fisheries for cephalopods. In: *Advances in Assessment of World Cephalopod Resources*. Caddy, J. F. (Ed.). *F.A.O. Fish. tech. Pap.* **231**: 145-203.
- SAUER, W. H. H. 1991 - Population characteristics of the chokker squid, *Loligo vulgaris reynaudii*, and its distribution in the Algoa Bay - St Francis Bay area in relation to environmental conditions. M.Sc. thesis, University of Port Elizabeth: 87 pp.
- SAUER, W. H. H. 1995 - The impact of fishing on chokka squid *Loligo vulgaris reynaudii* spawning concentrations on inshore spawning grounds in the South-Eastern Cape, South Africa. *S. Afr. J. mar. Sci.* **16**: 185-193.
- SAUER, W. H. H. and M. R. LIPINSKI 1990 - Histological validation of morphological stages of sexual maturity in chokker squid *Loligo vulgaris reynaudii* D=Orbigny (Cephalopoda: Loliginidae). *S. Afr. J. mar. Sci.* **9**: 189-200.

- SAUER, W. H. H. and M. J. SMALE 1991 – Predation patterns on the inshore spawning grounds of the squid *Loligo vulgaris reynaudii* (Cephalopoda: Loliginidae) off the south-eastern Cape, South Africa. *S. Afr. J. mar. Sci.* **11**: 513-523.
- SAUER, W. H. H., SMALE, M. J. and M. R. LIPINSKI 1992 - The location of spawning grounds, spawning and schooling behaviour of the squid *Loligo vulgaris reynaudii* (Cephalopoda: Myopsida) off the Eastern Cape coast, South Africa. *Mar. Biol.* **114**(1): 97-107.
- SMITH, S. J., HUNT, J. J. and D. RIVARD (Eds.) 1993 – *Risk Evaluation And Biological Reference Points For Fisheries Management*. *Can. Spec. Publ. Fish. Aquat. Sci.* **120**: viii + 442 pp.
- SIMON, F., ROCHA, F. and A. GUERRA 1996 - The small-scale squid hand-jig fishery off the northwestern Iberian Peninsula: application of a model based on a short survey of fishery statistics. *Fish. Res.* **25**: 253-263.
- SRINATH, M. 1991 - Letters to the Editor. *Fishbyte* **9**(1): p. 2.
- SUNILKUMAR MOHAMED, K. 1996 - Estimates of growth, mortality and stock of the Indian Squid *Loligo duvauceli* Orbigny, exploited off Mangalore, southwest coast of India. *Bull. mar. Sci.* **58**(2): 393-403.
- TINGLEY, G. A., PURCHASE, L. V., BASSON, M., ROSENBERG, A. A., ANDERSON, J. and J. R. BEDDINGTON 1990 - 1989 Annual Report on The Falkland Islands Fishery. Renewable Resources Assessment Group, Imperial College, London, 37 pp.
- TINGLEY, G. A., BASSON, M., PURCHASE, L. V., BRAVINGTON, M. V., DIAZ DE LEON, A. J. and J. R. BEDDINGTON 1992 - The Falkland Islands Fishery: 1991 Annual Report. Renewable Resources Assessment Group, Imperial College, London: 41 pp.

UOZUMI, Y., HATANAKA, H., SATO, T., AUGUSTYN, C. J., PAYNE, A. I. L. and R. W. LESLIE. 1984 – Report on the Japan/South Africa joint trawling survey on the Agulhas Bank in November/ December 1981. *Publ. Far Seas Fish. Res. Lab., S Series 11*: 91 pp.

WESTRHEIM, S. J. and R. P. FOUCHER 1985 – Relative fishing power for Canadian trawlers landing Pacific cod (*Gadus macrocephalus*) and important shelf cohabitants from major offshore areas of western Canada, 1960-1981. *Can. J. Fish. aquat. Sci.*, **42** (10): 1614-1626.

ZAR, J. H. 1984 - *Biostatistical Analysis*, 2nd ed. Englewood Cliffs, New Jersey; Prentice-Hall, Inc.: 718 pp.

Appendix

Catch and CPUE data from the jig and trawl fisheries

Table I: Monthly catch and CPUE from the jig fishery

<i>Year</i>	<i>Month</i>	<i>Catch (tons)</i>	<i>JIG CPUE (Kg/man/h)</i>
1985	1	77.0	5.878
1985	2	28.3	0.703
1985	3	12.0	10.352
1985	4	179.1	13.847
1985	5	34.1	10.622
1985	6	27.3	6.916
1985	7	7.8	4.730
1985	8	44.0	5.085
1985	9	272.7	4.923
1985	10	455.6	4.611
1985	11	809.2	4.673
1985	12	676.6	6.237
1986	1	150.4	3.643
1986	2	70.7	3.533
1986	3	27.3	1.163
1986	4	23.8	1.236
1986	5	91.4	2.670
1986	6	427.3	4.151
1986	7	744.5	3.167
1986	8	856.4	2.879
1986	9	491.6	2.496
1986	10	215.9	2.006
1986	11	138.1	1.768
1986	12	255.8	3.324
1987	1	128.3	2.399
1987	2	38.9	2.341
1987	3	2.8	0.920
1987	4	5.5	1.094
1987	5	13.4	0.959
1987	6	155.2	2.757
1987	7	352.7	2.698
1987	8	83.4	1.445
1987	9	224.5	2.789
1987	10	589.0	3.438
1987	11	499.8	4.008
1987	12	702.8	6.184
1988	1	80.4	3.284
1988	2	13.5	1.721

1988	3	119.6	3.224
1988	4	70.3	2.676
1988	5	52.4	1.662
1988	6	37.7	1.586
1988	7	200.5	2.110
1988	8	523.8	2.656
1988	9	782.7	3.016
1988	10	1174.2	3.680
1988	11	31.6	2.439
1988	12	1782.9	5.418
1989	1	936.4	4.046
1989	2	261.7	2.783
1989	3	833.7	5.597
1989	4	626.5	3.658
1989	5	806.2	3.658
1989	6	1721.6	5.681
1989	7	1075.6	4.783
1989	8	1039.0	5.064
1989	9	1146.2	6.937
1989	10	979.4	4.721
1989	11	5.2	39.242
1989	12	343.5	3.625
1990	1	166.6	3.148
1990	2	166.3	3.775
1990	3	276.0	3.648
1990	4	167.5	3.090
1990	5	13.7	0.420
1990	6	12.5	0.816
1990	7	68.8	2.158
1990	8	371.4	2.021
1990	9	720.8	2.368
1990	10	617.3	2.747
1990	11	15.2	5.267
1990	12	692.3	2.857
1991	1	32.5	1.724
1991	2	64.9	1.730
1991	3	96.6	1.749
1991	4	288.5	2.171
1991	5	48.8	1.374
1991	6	295.0	2.729
1991	7	724.3	2.984
1991	8	394.0	1.771
1991	9	1444.4	3.507
1991	10	1224.7	3.831
1991	11	1360.6	5.097

1991	12	725.8	4.139
1992	1	73.4	1.886
1992	2	84.1	3.903
1992	3	70.2	2.184
1992	4	26.5	1.166
1992	5	7.1	0.936
1992	6	117.8	2.565
1992	7	43.0	0.993
1992	8	165.1	1.756
1992	9	261.0	1.543
1992	10	107.3	1.355
1992	11	339.2	3.797
1992	12	238.8	4.236
1993	1	202.4	3.145
1993	2	283.6	2.162
1993	3	46.8	1.627
1993	4	243.9	3.017
1993	5	238.5	2.233
1993	6	373.3	2.631
1993	7	597.7	2.384
1993	8	607.6	2.599
1993	9	446.5	2.179
1993	10	254.6	2.051
1993	11	781.8	4.826
1993	12	2175.0	8.416
1994	1	1664.0	6.530
1994	2	468.9	4.930
1994	3	238.3	2.630
1994	4	275.8	2.680
1994	5	171.0	1.620
1994	6	444.3	4.000
1994	7	497.3	2.620
1994	8	178.7	1.270
1994	9	225.3	1.540
1994	10	369.9	2.070
1994	11	789.0	5.380
1994	12	853.0	3.660
1995	1	981.8	3.550
1995	2	368.5	2.800
1995	3	348.0	2.150
1995	4	302.0	2.570
1995	5	615.0	2.730
1995	6	515.0	2.150
1995	7	400.9	1.950
1995	8	330.7	1.650

1995	9	538.5	1.750
1995	10	968.4	2.900
1995	11	432.5	2.640
1995	12	981.3	2.740
1996	1	734.1	2.330
1996	2	422.2	1.780
1996	3	704.2	2.120
1996	4	601.2	1.900
1996	5	835.3	2.480
1996	6	458.6	1.570
1996	7	253.3	1.070
1996	8	508.1	1.480
1996	9	489.9	1.560
1996	10	453.8	1.480
1996	11	583.1	3.700
1996	12	942.1	2.300

Table II: Catches per period for the trawl fishery.

Year	Jan-Mar (tons)	April-Dec (tons)
1971	27	46
1972	187	325
1973	342	595
1974	1322	2300
1975	1332	2317
1976	770	339
1977	1205	2097
1978	1021	3968
1979	2081	3035
1980	1007	2047
1981	1719	2037
1982	1537	2067
1983	2305	1810
1984	587	1528
1985	1633	2054
1986	223	715
1987	238	414
1988	169	652
1989	413	750
1990	290	455
1991	142	351
1992	90	197
1993	51	227
1994	220	267
1995	125	214
1996	155	206

Table III: trawl CPUE (kg/h) for two periods

Year	trawl CPUE (kg/h)	
	Jan-Mar	Apr-Dec
1978	12.995	7.817
1979	20.838	8.772
1980	13.425	4.369
1981	17.125	10.153
1982	19.031	5.421
1983	22.999	2.868
1984	6.924	3.685
1985	10.668	2.816
1986	4.056	2.372
1987	3.721	1.628
1988	3.41	2.671
1989	7.105	3.199
1990	4.421	1.646
1991	3.62	1.972
1992	2.087	1.253
1993	1.863	1.496
1994	4.023	1.471
1995	2.76	1.42
1996	2.802	1.482

Table IV: Catches per period for the jig fishery

Year	Jig catches (tons)	
	Jan-Mar	Apr-Dec
1983	85.2	414.8
1984	170.4	829.6
1985	124	2976
1986	238	3162
1987	167.8	2628.2
1988	193	4633
1889	2056	7735.7
1990	623.6	2658.4
1991	201	6499
1992	388.2	2199.8
1993	567.7	5740.3
1994	2512	3929
1995	1781	5069
1996	1863	5037

Table V: jig CPUE for two periods

Year	jig CPUE(kg/man/h)	
	Jan-Mar	Apr-Dec
1985	2.152	5.08
1986	2.93	2.825
1987	2.324	3.484
1988	3.075	3.597
1989	4.283	4.863
1990	3.527	2.453
1991	1.738	3.396
1992	2.459	2.433
1993	2.375	3.658
1994	5.382	2.808
1995	2.979	2.363
1996	2.104	1.889

